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REUSEABLE LIGHT WEIGHT MODULAR
MULTI-LAYER INSULATION FOR SPACE SHUTTLE

by K. F. Burr

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UNION CARBIDE

LINDE DIVISION

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Project Manager, James R. Barber, Liquid Rocket Technology Branch
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16. Abstract

The adaptation of the Self Evacuating Multilayer Insulation (SEMI) System to space shuttle on-orbiter LH_2 tankage was investigated. Small scale material screening tests and subscale panel tests demonstrated the insulation's potential for withstanding the anticipated 100 flight cycles. The outer surface temperature upon re-entry was assumed to be +300°F. (149°C) for two hours each flight, or a total of 200 hours for the life of the system. The System tested utilized a heat formable casing (vacuum barrier) material (.3 mil (0.076 mm) polyester film) bonded with a room temperature curing RTV rubber. A composite spacer material (sliced open cell polyurethane foam and thin glass mat) was used as a separator between double aluminized Kapton and Mylar thermal radiation shields. A condensible filler gas (GN_2) within the sealed panel condenses when the panel is placed in contact with the LH_2 tankage thus reducing panel pressure and making it self-evacuating.

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1.0 SUMMARY

The purpose of this program was to determine if the Self Evacuating Multilayer Insulation (SEMI) System could be adapted to space shuttle orbiter vehicle cryogenic tankage. The SEMI system consists of a flexible vacuum casing enclosing alternate layers of reflective thermal radiation shielding and spacer materials. A gas condensible LH_2 temperature provides the self-evacuating mechanism within the panel. The SEMI system was previously developed for service on a one flight vehicle. Through material substitutions, alteration of the system was sought which would allow it to withstand the higher expected surface temperatures (+300°F, 149°C) as well as mechanical and thermal cycling typical of conditions encountered during launch and re-entry over the required 100 flight life expectancy. However, the totally self-evacuating characteristic of the SEMI system had to be compromised. Some system impermeability had to be sacrificed in selecting a formable and temperature resistant panel casing material. Intermittant evacuation of the system has been proposed as a possible alternate to the previous long (30 day) pre-launch panel storability.

The system tested consisted of an easily formable vacuum casing (3 mil, (.076mm) type 300 S Mylar Polyester film) bonded with a room temperature curing RTV rubber adhesive (Dow Corning 732 RTV). A composite spacer material of sliced open-cell polyurethane foam and thin glass mat was used as a separator between double aluminized Kapton and Mylar thermal radiation shields. A condensible filler gas (GN_2) within the sealed panel condenses when the panel is placed in contact with the LH_2 tankage, thus producing a reduced pressure, and a "self-evacuating" panel.

Small scale materials evaluation and screening tests were performed in an effort to isolate those materials which would allow the hot side of the insulation to operate at an ambient surface temperature of +300°F (149°C) for a time equivalent to 100 flight cycles (estimated to be about 200 hours). Subscale insulation system tests provided on evaluation of combined thermal and mechanical cycling effects on subscale insulation panels. Fabrication techniques were demonstrated on a large scale demonstration panel.

The work covered by this report was of a gross feasibility nature, and results, while indicating some potential for a workable system, are both limited and preliminary. A thorough and quantitative definition of the system would require considerable development to ascertain reproducibility in materials and system behavior, develop reliable manufacturing techniques, and to generate accurate system design data.

2.0 INTRODUCTION

Storage of cryogenic liquids plays an important role in the further exploration of space. Development of a light weight high performance insulation is necessary to reduce launch lift-off weights. Union Carbide Corporation, Linde Division, under the direction of NASA Lewis Research Center in Cleveland, Ohio has been developing and evaluating a Self Evacuating Multilayer Insulation (SEMI) System for the past several years. The work described by this report, performed under Contract NAS 3-14366, is an extension of previous efforts by UCC Linde Division on Contracts NAS 3-12045, NAS 3-6289 and NAS 3-7953. The objective of this work was to determine if the SEMI system concept could be up-graded for use on the space shuttle orbital maneuver system (OMS) LH_2 tankage. The SEMI system was previously developed for service on a single use vehicle. It is now desirable to show that the SEMI system, with some material substitutions, can operate at the higher expected outer surface temperatures encountered during launch and re-entry over a 100 flight life expectancy. System evaluations consisted of small scale materials evaluation tests and subscale panel system evaluation tests.

The SEMI panel consists of a layered composite of doubly aluminized Kapton or Mylar thermal radiation shields separated from each other by lightweight, low thermal conductivity spacer materials (open-cell foam or glass mat), enclosed in a gaseous nitrogen atmosphere by a leak tight outer casing (Figure 1). These panels are installed on the surface of a cryogenic tank in such a manner that a portion of every panel is in contact with the tank surface (Figure 2). Upon filling the tank with the cryogen to be stored, the cold portion of each panel acts as a cryopump, evacuating the panel. UCC Linde Division has investigated cryopumpable shingled three-layered systems of panels on previous contracts (Ref. 1-3).

This program was divided into three main areas of work, small scale materials screening and evaluation tests, subscale panel cycling tests, and large scale insulation system design.

Shuttle configuration information was obtained from Grumman Aerospace Corporation, Bethpage, New York; McDonnell Douglas Corporation, St. Louis, Missouri; and North American-Rockwell Corporation, Space Division, Downey, California. Radiation shield material emittance tests as well as a thermal analysis to determine insulation hot side temperature were performed under contract by Grumman Aerospace Corporation.

The work on this contract was performed under the direction of the National Aeronautics and Space Administration, Liquid Rocket Technology Branch, Lewis Research Center, Cleveland, Ohio. The technical monitor was Mr. J. R. Barber. The UCC Linde Division program manager was Mr. K. F. Burr.

Other Linde Division personnel contributing to this effort included Mr. L. R. Niendorf, Mr. G. E. Nies, Mr. F. Notaro, and Mr. N. R. Wertz.

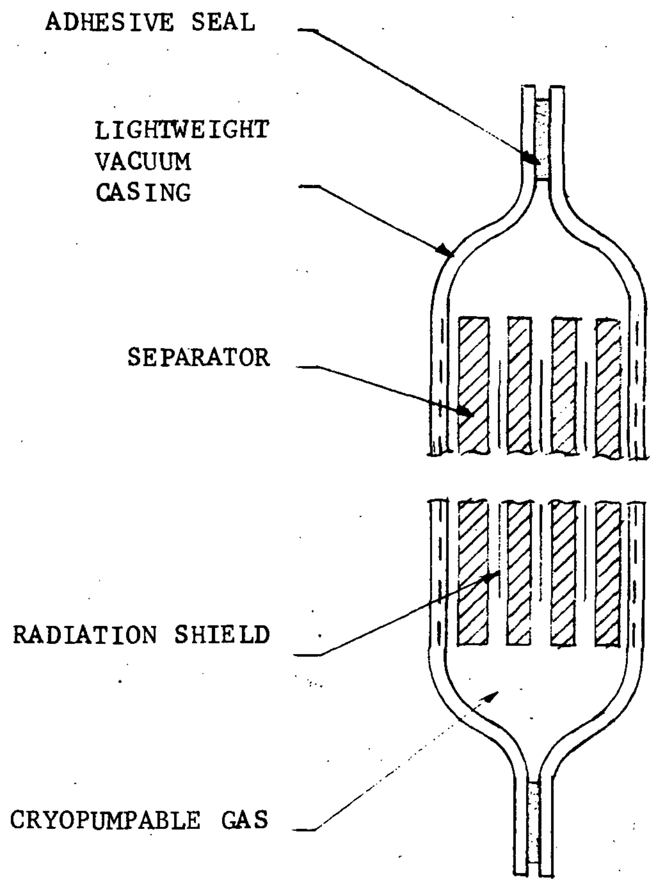


FIGURE 1. SCHEMATIC OF SEMI PANEL SHOWING COMPONENT MATERIALS

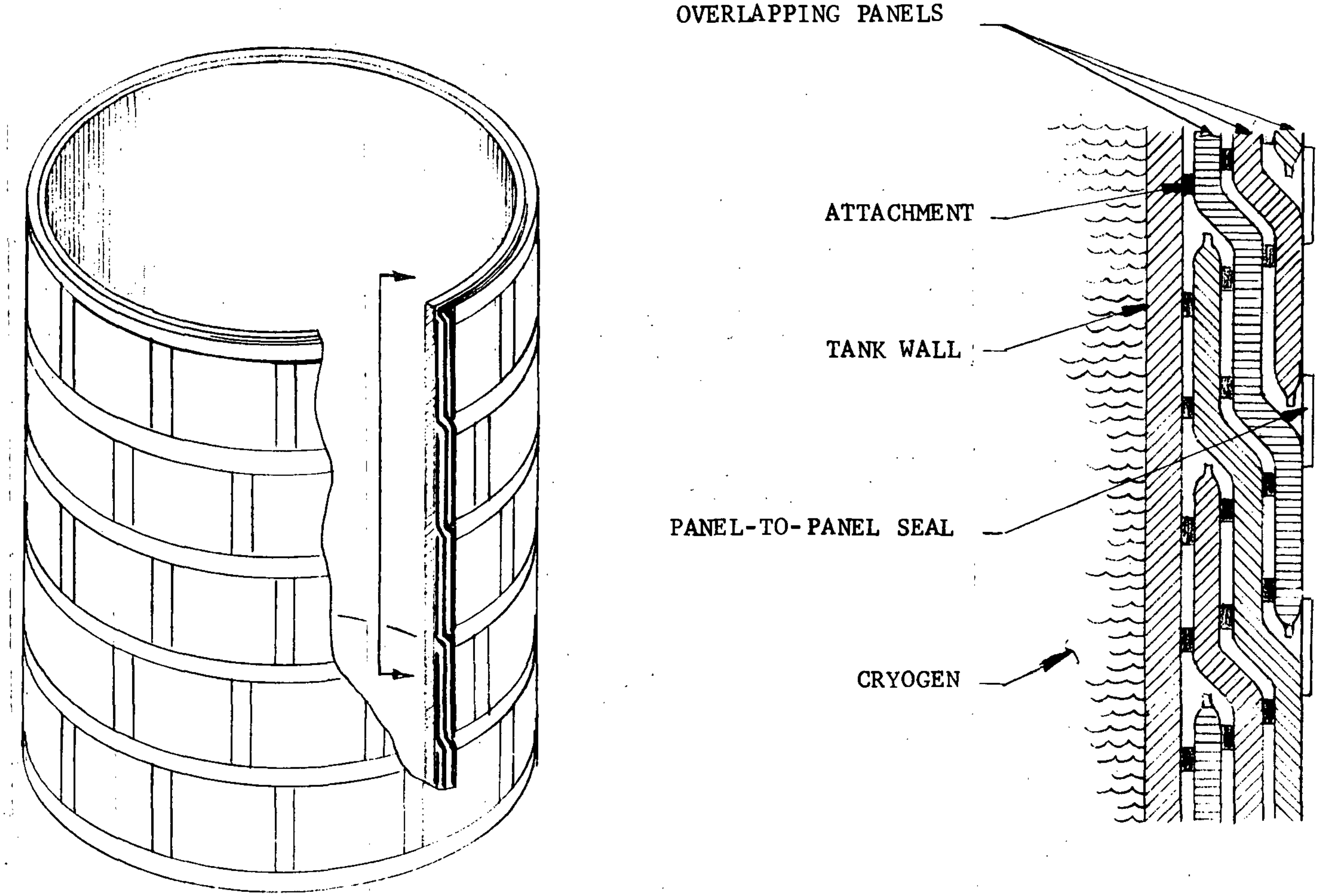


FIGURE 2. SEMI PANEL SHINGLE ARRANGEMENT INSTALLATION

3.0 DISCUSSION OF RESULTS

Five different classes of casing materials were subjected to high temperature (+300°F, 149°C) compatibility tests, i.e. heat stabilized Nylon 6, high temperature polyester, FEP Teflon, Polysulfone, and Kapton films. Results of these tests showed that Nylon and Polysulfone tended to become brittle after extended (50 hours or more) exposure to the high temperature. Adhesive bonding difficulties made Teflon unsuitable. Kapton has outstanding temperature resistance. However, its extremely low tear strength and difficult forming procedure also precluded its use. The polyester material on the other hand, demonstrated thermal stability at 300°F (149°C) for the required 200 hours, was bonded using an RTV rubber adhesive, and was readily vacuum formed with a wooden mold and heat gun. Subscale test results for the polyester/RTV panel indicate the panels have the potential to withstand thermal and mechanical cycling. Adhesive test results suggest the thickness must be kept below 10 mils (.25 mm) to retain flexibility.

3.1 CONCLUSIONS

1) The SEMI system of cryopumpable pre-fabricated insulation panels has potential for application to space shuttle orbital maneuver system (OMS) tankage for a 100 cycle design life. The self-evacuating concept had to be compromised in order to meet objectives, however. The system's potential to withstand mechanical and thermal cycling was demonstrated under this contract. Additional development is required to assure reproducibility of results and further develop manufacturing techniques.

2) The single layer casing concept can simplify fabrication of insulation panels. Long storage times are not detrimental to performance provided GN_2 is used as the filler gas. However, provision must be made for space evacuation of the panels on each flight to prevent excessive pressure rise upon panel warm-up. This constitutes a compromise in the self-evacuatability of the panels.

3) The single layer 3 mil (.076 mm) type 300 S Mylar polyester casing/732 RTV adhesive system provides best overall performance from a cycling and handling standpoint.

4) The 732 RTV adhesive is suitable at the upper service limit of the panels (+300°F, 149°C) and maintains flexibility at LN_2 temperatures if joint thickness is kept below 10 mils (.25 mm).

4.0 ANALYSIS AND TEST PROCEDURES (Tasks I - V)

4.1 SEMI Requirements for Space Shuttle (Tasks I, III)

4.1.1 Configuration Requirements

In order to insure that the present SEMI system development work would be directed toward solutions of problems that would be encountered in shuttle applications, the various contractors involved in shuttle configuration studies were contacted. Contractors called upon included Grumman Aerospace, Bethpage, New York; McDonnel Douglas Corporation, St. Louis, Missouri; North American Rockwell Corporation, Space Division, Downey, California.

General system requirements as outlined by these contractors included the following: (1) L/D ratios for the liquid fuel tanks are variable; however, probable final designs will incorporate cylindrical and/or spherical shapes. For our studies, an assumed L/D ratio of 1.5 was used. (2) Several penetrations through the insulation system of 4 inches (10.2 cm) in diameter or less will be encountered in the tank design. (3) Tank support within the shuttle will be via struts with conical or cylindrical support skirts. (4) Manways will likely be included in the tank design. Their configuration, size, and servicing requirements were left flexible. Design conditions are summarized in Table I.

Table I

Summary of On-Orbiter LH_2 Tankage Requirements

Tank surface area	1000 ft^2 (92.9 m^2)
Tank volume	2300 ft^3 (65.1 m^3)
LH_2 net weight	10,000 lbs. (4536 Kgm)
Insulation Penetration Feedthrough Diameter	2-4 inches (5-10 cm)
Design temperature limits	
SEMI Outer surface	350°F (177°C)
SEMI Inner surface	-423°F (-253°C)

4.1.2. Thermal Requirements

Previous SEMI systems, developed and tested under contracts NAS-3-12045, NAS 3-7953, and NAS 3-6289, operating over a temperature range of +100°F (38°C) to -423°F (-253°C) have demonstrated a ground hold flux of 10 BTU/hr-ft^2 (31.5 watts/m^2) and a space condition heat flux of .63 BTU/hr-ft^2 (1.99 watts/m^2) for an installed insulation thickness of 1.5 inches (3.8 cm). It was assumed that the same heat flux will be required for the shuttle system, having an operating temperature boundaries of +300°F (149°C) to -423°F (-253°C), while the insulation is compressed under a pressure of

one atmosphere. Since the insulation is compressed during this high temperature exposure, solid conduction through the spacers will be the primary mode of heat transfer (Radiation is essentially completely attenuated).

In order to determine the upper limit design temperature for the insulation system, Grumman Aerospace Corporation was contracted to perform a preliminary study of the temperatures encountered by the shuttle vehicle during re-entry. Grumman's study (see appendix 6.1) indicated a maximum temperature of 150°F (65°C) on the outer surface of the SEMI system. The analysis was performed using temperature profile and tank location design for the Grumman proposed H33 vehicle at a point on the windward side, 20 feet (6.1 m) from the nose tip. The external thermal protection system (TPS) and internal microquartz insulation were included in the analysis. As noted on Figure 3, the maximum temperature of less than 150°F (66°C) on the external surface of the SEMI system is not reached until approximately 35 minutes after touchdown. The initial assumed temperature of 100°F (38°C) at the beginning of re-entry (t = 0 seconds) was supplied by Grumman.

4.1.3 Casing Requirements

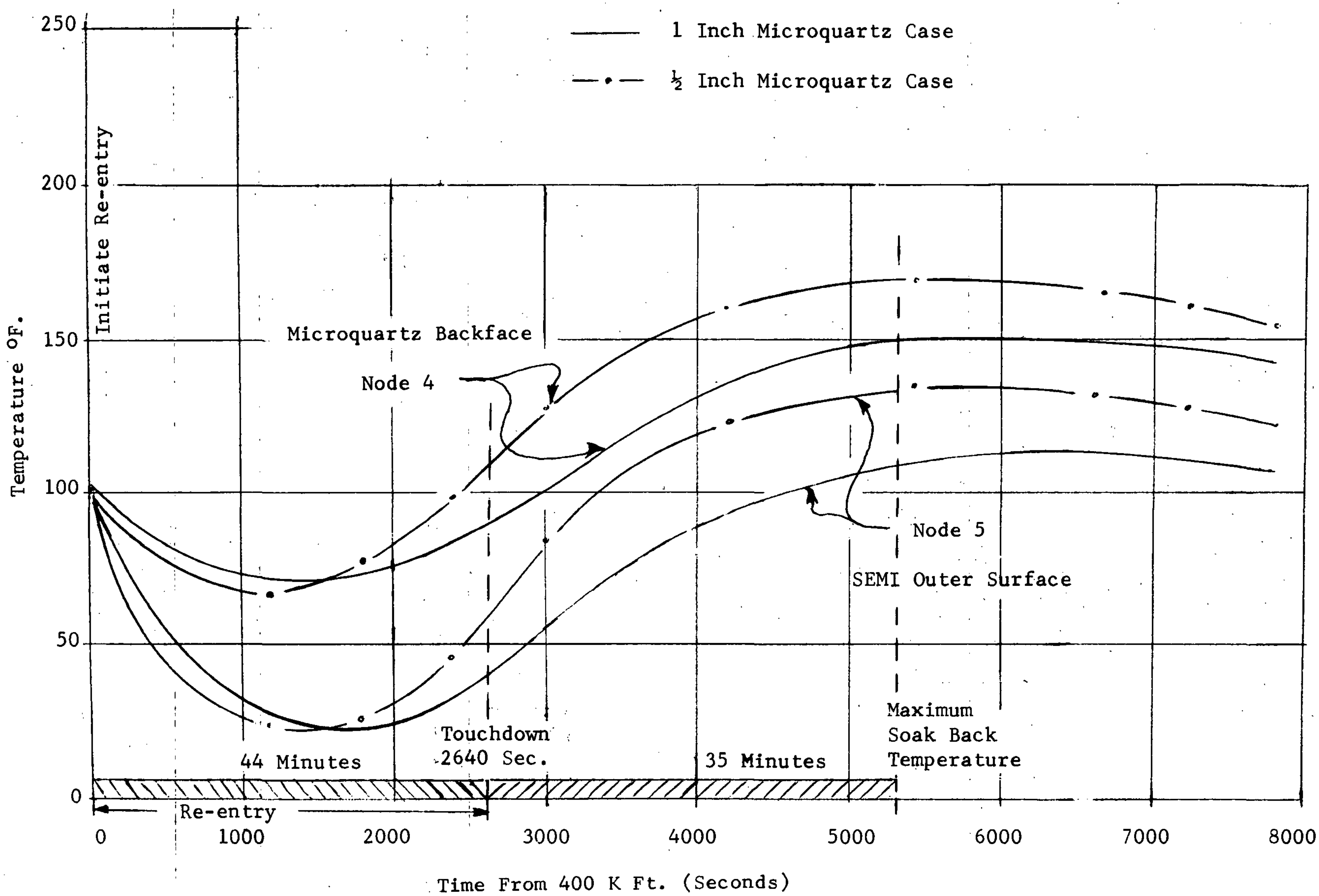
The casing material must be capable of operating in the expected temperature/vacuum environment while retaining the required SEMI system characteristics. For example, the casing must demonstrate leak tightness, flexibility and low lateral thermal conductivity before and after the anticipated pressure and temperature cycling.

The previous SEMI system casing (see References 1-3) was a 4-ply laminate of aluminized Mylar. This system was suitable for cryogenic (-423°F, -253°C) to ambient (+100°F, 38°C) temperature. The previous casing material, however, is not capable of withstanding the 300°F (149°C) operating requirement for the shuttle. A high temperature plastic film is required. Initial efforts were directed toward substitution of Kapton into the previous casing design, i.e. a multi-ply laminate of metallized Kapton film. However, the Kapton laminate candidates were found deficient in layer peel strengths and permeability. In addition, they contained numerous wrinkles which made it difficult to construct vacuum tight trouble free joints. These problems made it necessary to re-evaluate the SEMI system operating characteristics and requirements.

The original SEMI system was designed for a single use vehicle, with ambient temperature storage capability and no refurbishment or repair required. Its one time use dictated that the panels perform well when compressed under a one atmosphere pressure, and then demonstrate excellent performance in a space environment, i.e. uncompressed. Minimum casing material permeability for this system was determined as that which was required to permit panel evacuation, back-fill, and installation within 30 days without contamination of the filler gas. This required the externally exposed casing be a relatively impermeable material. This same

Figure 3

TEMPERATURE HISTORY (CALCULATED) ON-ORBIT LH_2 TANK



specification had been carried over to the multiple use shuttle SEMI system. However, difficulty in meeting this specification plus the added rigor of repeated use suggested the possible need for intermittant evacuation. Low panel permeability can be sacrificed if provisions are incorporated for initial and post flight evacuation of the insulation system. Permeability then must only be sufficient to prevent excessive gas input during pre-launch and re-entry periods.

On the ground prior to launch, the SEMI system must exhibit good thermal performance while under a one atmosphere compressive load. During launch, the insulation must withstand higher outer surface temperatures than previous panels while maintaining thermal performance. Once in space, performance without the compressive load must be excellent. Re-entry again brings increased outer surface temperatures and the compressive load. After landing, some type of refurbishment to parts of the shuttle is likely. This refurbishment time allows opportunity to re-evacuate or repair panels as necessary. Evacuation might be accomplished by manifolding the panels to each other and/or a service panel. This manifold system could also be used to allow pumping of the panels in space after launch. This periodic evacuation option greatly reduces the permeability requirements of the casing (permeability load must only be limited during the relatively short pre-launch, launch, and re-entry periods). This modification of the SEMI system concept allows consideration of a single layer, non-metallized plastic film casing. A side benefit of using a single layer film casing is that permeability requirements of the panel adhesive are also reduced allowing consideration of a one part silicone RTV adhesive for panel fabrication. Of significant importance also is that eliminating the aluminizing in the 4-ply casing also removes a lateral heat path through the panel, which will improve the total thermal performance in the order of 25%.

One possible disadvantage with this approach is that carbon dioxide could no longer be used as the cryopumping filler gas. The carbon dioxide would permeate out of the panel faster than atmospheric gas would be transferred in, thus in effect the panel would be self evacuating at any temperature. If the panels are backfilled with nitrogen gas, a more favorable balance between incoming and outgoing gas would result. A review of previous contract work indicates that nitrogen gas would be acceptable for use in SEMI panels installed on hydrogen tankage. Nitrogen was successfully cryopumped in work performed under contracts NAS 3-6289 and NAS 3-7953. It was found, however, that the expected 1-2 μ Hg pressure was achieved in a much longer time than for the carbon dioxide. For this reason the nitrogen was found undesirable for the single use system. However, with provisions for evacuation before and during flights through a manifold system, nitrogen becomes a suitable filler gas. The single layer casing concept therefore appears to be a compromise requiring the addition of a manifolding system to achieve higher casing temperature capability and ease of panel fabrication.

4.1.4. Shield And Spacer Requirements

The radiation shields and spacers must be capable of operating in the expected temperature/vacuum environment, while retaining their essential characteristics. The radiation shields must remain flexible and retain their low emissivity. The spacers must maintain sufficient resilience after many compression cycles while exhibiting very low thermal conductivity, low off-gassing, high gas flow conductance, and low density.

Mylar and Kapton shields were examined. Economic considerations favor the use of Kapton only where required to meet high temperature requirements (above 150°F, 66°C) and aluminized Mylar for the lower temperature regions.

High temperature Mylar polyester was not used for the high temperature radiation shields due to the availability of aluminized Kapton. However, it is anticipated that this material would function adequately in this application.

The thin open-cell polyurethane foam layers used on previous work are adequate for the low temperature (-423°F, 253°C to 100°F, 38°C) portion of the panel. A 1/8 inch (.32 cm) Dexiglas mat was used for the hot region spacer material.

4.2 MATERIAL AND COMPONENT SCREENING TESTS (Tasks, II, III)

4.2.1 MATERIAL SCREENING TESTS

4.2.1.1 Casing Tests

Initial efforts at obtaining a suitable 4-ply Kapton laminate met with little success. The laminates obtained from National Metallizing all showed very low laminate peel strength which resulted in layers sliding relative to each other when stretched or heated. In addition numerous "tunnels" between layers made it extremely difficult to fabricate leak free panels. The main single layer casing materials investigated included Kapton, Polyester, and Nylon. Material properties are summarized in Table 2.

Examination of Table 2 suggests two main areas of comparison among the candidate materials. i.e. handling and/or fabrication of the film, and temperature limitations. Referring to the material tear strengths, it can be seen that all of the candidates (except polysulfone) have about the same initiation tear strength. However, the fluoroplastics and Nylon stand out as having relatively high propagation tear strengths. A high material propagation tear strength reduces the probability of nick propagation and tearing problems which might be encountered during panel handling. (Note the extremely low strength for Kapton). Looking next at the maximum percent elongation we see again that Nylon stretches easily, and therefore could be expected to easily vacuum form.

Table 2

Casing Material Properties

	Property (Trade Literature)	Kapton	Mylar	Heat Stab. (A) Nylon 6	Hi Temp. (B) (Polyester)	FEP (C) (Teflon)	PTFE (C)	Polysulfone
1.	Max. Cont. Serv. Temp., °F.	550	300	300-400	300-400	400	400-500	350
2.	Min. Cont. Serv. Temp., °F.	-450	-450	-100	-320 *	-425	-150	-100
3.	Tear Str.-(Propagation) gm/mil.	8	15	35-50	30	125	10-100	9-12
4.	Tear Str.-(Initiation) #/In.	1,126	1,300	1,200	3,000	1,100	-	240
5.	Tensile Str., psi (70°F.)	25,000	20,000	11-15,000	20-35,000	2500-3000	1500-4500	8400-10,600
6.	% Elongation (70°F.)	70	120	400-500	100	300	100-350	64-110
7.	Folding Endurance (70°F.)	10,000	20,000	>250,000	>100,000	4000	-	-
8.	Permeability, cc/100 in^2/mil/24 hrs/atm @ 25c N_2	6	0.9	0.35	0.9	320	-	40
	O_2	25	5.7	5	5.7	750	-	230
9.	Thermal Cond. BTU-ft/hr-ft^2-°F.	.09	.022	0.1	0.1-.12	0.11	0.14	1.5
10.	Coef. of Th. Exp., in/in-°F x 10^{-5}	1.11	0.944	4.8	3.9-5.6	5.85	5.5	3.1
11.	Specific Gravity	1.42	1.40	1.14	1.39	2.15	2.2	1.24
12.	Heat Sealing Temp., °F.	Not Heat Sealable	Not Heat Sealable	450	490	540-700	-	500-550
13.	Adhesive Bonding	Silicone RTV	No problem anticipated	Possible problem although adhesive available	No problem anticipated	Possible if etched		No problem anticipated
14.	Cost $/.001 in-ft^2	0.228	0.022	0.013	0.009	0.089	.08	0.006
15.	Comments	Difficult to form, tears easily, expensive. good high & low temp. properties.	Easy to form tears easily good low temperature properties.	Forms easily; good high temperature properties; marginal low temp. prop. Bonding possible problem; fair tear resistance.	Easily formed fair tear resistance; good high and low temp. properties; Best overall prospect.	Good high and low temp. and forming properties; bonding a problem		Marginal hi and low temp. prop. forms easily, tears easily

A. Similar to Capran (Allied Chemical) or Reynolon (Reynolds)

B. Similar to Look Roasting Film or Celenar (Celenese Plastics) or Glad (Union Carbide) of Mylar (DuPont)

C. Additional cost to etch material for bondable surfaces ~ $0.50/ft^2

* UCC Linde Tests

Teflon exhibits better low temperature properties than Nylon, but both are difficult to bond. The polyester material on the other hand exhibits a fair propagation tear strength. Its high temperature properties are adequate and can be relatively easily bonded. Low temperature flexibility was demonstrated by fabricating an envelope of the material and filling it with LN_2. The bag was then manually flexed many times with no apparent damage to the material. The conclusion drawn from Table 2 is therefore that the polyester material is the best overall candidate for the SEMI panels.

4.2.1.1.1 Forming Tests

In order to produce vacuum tight SEMI panels, it is necessary to have good adhesive joints along the edges of the panels. Fabrication of these joints require smooth flat surfaces between which the adhesive is placed. Having the casing edges flat minimizes air bubbles and voids in the adhesive line during its manufacture. On previous contracts, the 4-ply Mylar casing was vacuum formed over a wooden mold using a heat gun. However, Kapton laminate and Kapton film can not be adequately formed this way. Small scale forming tests indicated that single layer 1 mil (.025 mm) Kapton could be drawn successfully by vacuum forming at 400°F (204°C), followed by a slow cooling at room temperature. The material, however, relaxes and loses its set when reheated to 350°F (177°C) under no load. A permanent set was obtained by increasing the forming temperature to 600°F (316°C) after which the casing was cooled quickly by quenching with water. This set was permanent and was not lost when subsequently reheated to 350°F (177°C) under no load. This heat/quench method of forming was the method used to form all single layer Kapton casings, although, the temperature was increased to about 800°F (427°C).

Some problems were encountered in handling the drawn Kapton film. Polyimide film has a very low tear propagation resistance (see Table 2) and thus is quite sensitive to any nicks or notches in it. The result of low tear propagation strength is panel joints which can tear quite easily even during normal handling.

Forming techniques for other casing materials were also investigated. Small scale forming tests on Nylon and polyester materials were conducted. The objective of these forming tests was to develop a simple technique of drawing the casings into the desired shape with a minimum of time and effort. Wooden forms were used whenever possible because of ease of fabrication and handling. Two types of drawing forms were tried, i.e. male and female forms. Success was achieved when drawing 2 mil (.05 mm) Nylon film on both of these forms although the female mold provided a flatter and smoother surface for bonding. Localized heating, i.e. with a heat gun, produced adequate stretching over the wooden forms. However with localized heating, all the stretching is concentrated in the heated areas, and consequently the material thins out appreciably during the draw increasing the possibility of casing rupture in these areas. Additional testing with 3 mil (.076 mm) casing material showed more acceptable results since more material was available to be drawn resulting in less thin-down.

The polyester material appeared somewhat stiffer and stronger than the Nylon and therefore more difficult to draw. Adequate forming was obtained with localized heating over a wooden mold for the basic panel outline. However, the localized heating technique did not provide sufficient stretching to form the small, sharp radius in a penetration area. Successful forming of this area was accomplished by using a metal form and higher drawing temperatures. The film to be drawn was allowed to soak at temperature (about 400°F, 204°C) for 10 to 15 minutes in an oven at ambient pressure. The sheet was then vacuum formed over a male mold. Figure 4 shows a trimmed polyester casing drawn on a Task IV polar panel form using this technique. Notice that all edges are smooth and have an absence of wrinkles. This heating/stretching technique allows the entire sheet to contribute to the stretching. The polyester casings were therefore fabricated in two parts, i.e., the basic panel outline formed with heat gun and wooden mold, and the penetration area "cup" formed in an oven. These two pieces were then bonded together to form a complete casing. Figure 5 shows the first Task II panel which utilized this two piece fabrication.

Ultimate panel manufacturing procedures would likely utilize a one piece forming technique with a metal mold in an oven at 400°F (204°C) (similar to the Task IV panels). This method however is impossible to achieve on a large scale without expensive metal forms and large ovens.

4.2.1.1.2 Temperature Exposure Tests

Long term (200 hour) continuous exposure tests were run on all candidate casing materials at 300°F (149°C) and 350°F (177°C). Post test analysis was of a subjective nature and consisted of visual inspection, weighing, and manual flexing. Results showed that the Kapton film remained relatively unaffected at both temperature, while the Nylon and polyester materials began to lose flexibility after about 50 hours at 350°F (177°C) and were quite brittle after 200 hours. At the lower temperature, i.e. 300°F (149°C), both the polyester and Nylon appeared to retain much of their flexibility. These tests suggest that the long term aging characteristics of the films are satisfactory only at or below a temperature of 300°F (149°C).

4.2.1.1.3 Helium Permeation Tests

During a given flight cycle, the panel casing material encounters several different environments which effect its permeation characteristics. For example, on the ground, the casing is at ambient temperature with an air permeation rate determined by the one atmosphere driving force. This pre-launch condition may last several hours. During the launch phase the casing temperature begins to rise, although lagging somewhat the outer vehicle temperature. At the same time however, the ambient pressure drops, reducing the permeation driving force. This launch condition may last several minutes. In space, there is no driving force and the casing material is cold. Whatever permeation takes place here will be out of the panel. It appears therefore, that the most important period to consider when dealing with casing permeation is the ground hold portion of each flight.

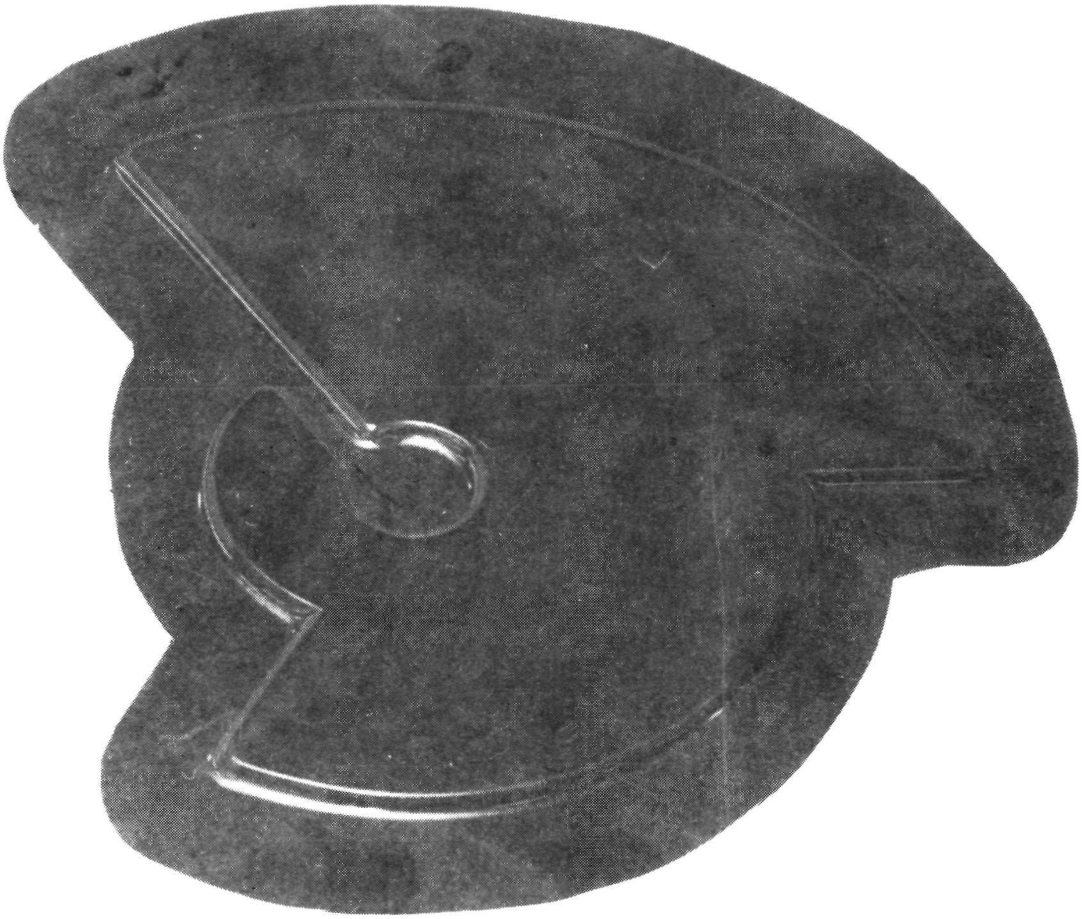


Figure 4

Trimmed Polyester Polar Panel Casing

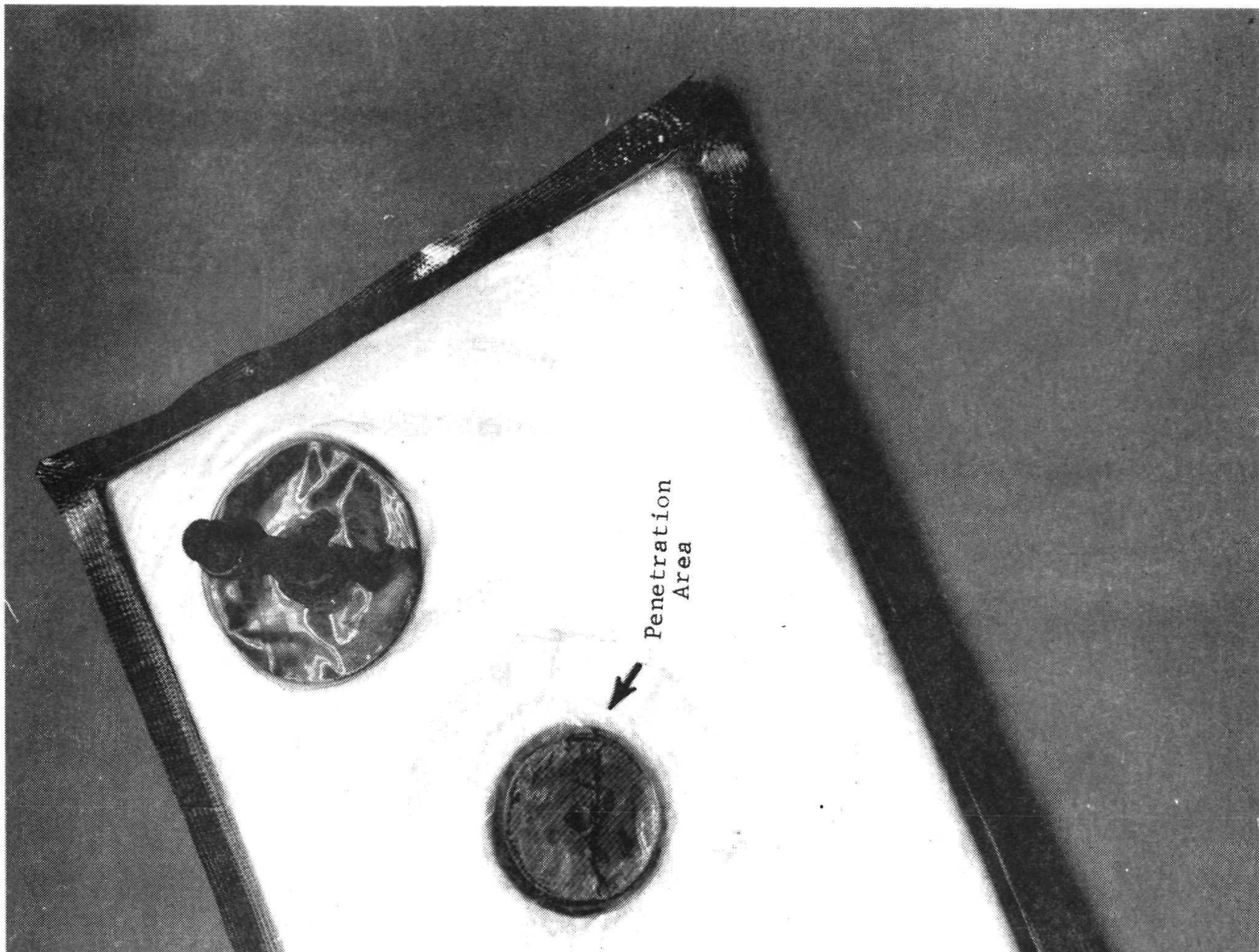


Figure 5
Polyester/RTV High Temperature Panel

Ambient temperature helium permeation tests were run on each of the candidate casing materials to determine their helium permeation characteristics. The permeation test consisted of placing a known concentration of Helium (a 0.1% He in N_2 mixture in this case) on one side of the sample and pumping the other side through a Veeco MS-9 Helium leak detector. By knowing the sample surface area and the leak detector calibration, a permeation rate can be determined for the sample. Permeation data for the various casing material tested is indicated in Table 3. Since Helium gas is the primary non-condensible found in the panels, these permeation values give useful information about the possible pressure rise characteristics of a panel. These permeation values are based on a 760μ Hg driving force and consequently the permeation values are higher than would be seen in air where the driving force is only 3.8μ Hg. For a SEMI system built of Mylar for example, a system Helium pressure rise of about 0.1μ Hg would be seen in about 8 hours of ground hold. This non-condensible Helium could be removed during refurbishment or while in flight by space pumping.

4.2.1.2 Adhesive Tests

The objective of the adhesive screening tests was to obtain an adhesive which would retain its strength and flexibility properties when exposed to the anticipated high and low temperature environments of the shuttle.

Screening tests to evaluate various adhesive systems for hot side conditions of 350°F (177°C) consisted of adhering 1 inch (2.5 cm) wide coupons of the casing film with the candidate adhesive and determining the ambient temperature strength of the cured joint in a 180° peel test (see Figure 6). All adhesive joints were fabricated according to manufacture recommended procedures, and heat aged overnight at 350°F (177°C) prior to testing at ambient temperature to note any short term temperature effects. Similarly, additional samples were soaked in liquid nitrogen, and then allowed to return to ambient temperature before testing. The criterion for adhesive peel strength acceptability was set at one fourth the tensile strength of the casing material. This requirement proved satisfactory on previous contracts.

Initial testing was directed toward finding a suitable adhesive for use with Kapton film. The various adhesive systems tested and a summary of Kapton test results are presented in Table 4. Adhesive assembly procedures are presented in Section 6.2. As a result of these tests, the Crest Products 7343/7139 urethane adhesive, and the one part Dow Corning 732 RTV were selected as possible candidates for both high and low temperature service. Vendor literature for the 732 RTV suggests its minimum service temperature is about -80°F (-62°C). However, as is the case with many adhesives, if the joint is kept thin enough, a degree of flexibility is maintained at low temperatures. Dow Corning 280A/adhesive was considered as a candidate adhesive to provide an ambient side seal between adjacent SEMI panels, i.e. for panel-to-panel seals. The adhesive could be applied to Kapton film, to produce a pressure sensitive tape which would adhere to clean untreated Kapton.

TABLE 3

Candidate Casing Helium Permeability Test Results

Material	He Permeability, atm-cc-mil/sec-ft^2 *
Kapton (Polyimide)	14.05×10^{-4}
Capran (Nylon)	12.92×10^{-4}
Reynolon (Nylon)	14.7×10^{-4}
Celenar (Polyester)	12.11×10^{-4}
Mylar (Polyester)	23.51×10^{-4}

NOTE: Permeation test section diameter - 6 1/4 inches.

* atm-cc-mil/sec-ft^2 of helium from a 0.1% He in N_2 mixture.

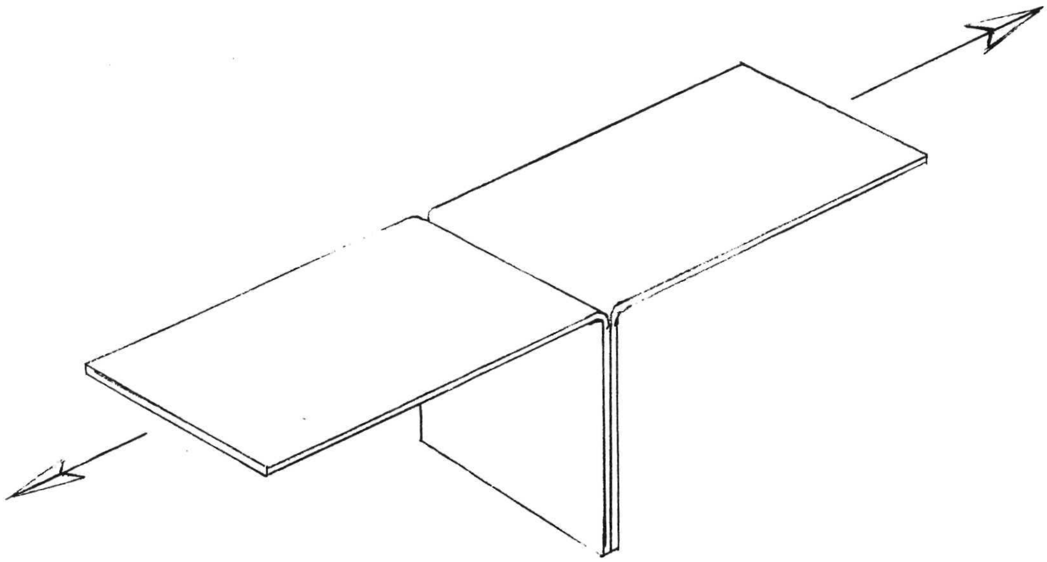


Figure 6 180° Adhesive Peel Test

TABLE 4

Summary - Screening Test Results-Adhesive Candidates
For Hot Side Kapton Casing Material Joints

Sample Size (Film) 1" x 4" x 2 mil thick*
Adhesive thickness as noted

(See Appendix III for procedures)

Manufacturer/ Product No.	Type of Adhesive	Peel Test of Cured Samples aged overnight at 350°F. and cooled to Room Temp. prior to 180° Peel Test		Failure	Effect of Adhesive on Film Strength	Effect of 350°F. Heat Overnight on the Adhesive	Total Laminate Thickness	Adhesive Thickness
		Overnight Heat lb./inch	Heat and LN_2 Shock lb./inch					
American Cyanamid Co. BXR-34B-32	Polyimide	2.5	3.0	Film Failure at adhesive line	Weakened Film	Slight darkening, many small gas bubbles.	.0096"	.0054"
Crest Products								
3135-7111	Epoxy	1.0	0.5	Cohesive** Failure	None	Small bubbles appeared, color change only slight, flexible, less bond strength than Matcote 1-02	.0067"	.0025"
3147-7125	Epoxy	0.1	0.6	Adhesive*** Failure	None	Very slight color change in center of coating, darker at edges.	.0066"	.0024"
7343-7139	Urethane	4.1	4.5	Cohesive Failure	None	Very slight color change	.0068"	.0026"
7344-7119	Epoxy, Flex.	2.1	3.2	Adhesive Failure	Weakened Film	Resin turned black, indication of breakdown of adhesive, bubbles.	.0069"	.0027"
3170-7133	Epoxy	0.4	0.3	Adhesive Failure	None	Dark brown discoloration of film substrate.	.0122"	.0080"
Dow Corning								
#280A (Sample 1)	Silicone Adhesive	6.9	5.1	Adhesive-will retack	None	Very little color change	.0143"	.0098"
#280A (Sample 2)	Pressure Sensitive	4.2	6.4	Adhesive-will retack	None	Very little color change	.0137"	.0095"
#732	Silicone RTV	1.8	2.1	Cohesive Failure	None	Very little color change	.0190"	.0147"

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* Measured Double Thickness of Film varies from .0042 to .0045 inch.

** Failure within the adhesive.

*** Failure at the interface between adhesive and film.

TABLE 4 - continued

Manufacturer/ Product No.	Type of Adhesive	Peel Test of Cured Samples aged overnight at 350°F. and cooled to Room Temp. prior to 180° Peel Test		Failure	Effect of Adhesive on Film Strength	Effect of 350°F. Heat Overnight on the Adhesive	Total Laminate Thickness	Adhesive Thickness
		Overnight Heat lb./inch	Heat and LN_2 Shock lb./inch					
3M Minnesota Mining & Mfg. #2214 HiTemp	Epoxy Al Filled	3.0	2.4	Film Failure in bond area	Weakened Film	Darkening of resin mix, small bubbles appeared, hard and brittle.	.0099"	.0057"
EC 3419	Epoxy Modified	2.4	2.1	Film Failure in bond area	Weakened Film	Considerable out-gassing on casing	.0061"	.0019"
AF-130 Film	Epoxy Prepreg.	1.5	2.8	Film Failure at adhesive line	Weakened Film	Mild darkening of resin, numerous bubbles were released from glass strands.	.0170"	.0128"
Matcote Co.,Inc. Matstick 1-02	Epoxy	1.8	2.2	Adhesive Failure	None	Very slight discoloring of resin, good appearance, flexible.	.0062"	.0020"
Flex. Blend Bakelite ERL-2770 Celanese #858	Epoxy	1.1	0.9	Adhesive Failure	None	Slight color change to light brown.	.0066"	.0024"
E.I. DuPont de Nemours Teflon FEP Film	Teflon	No Test	No Test	Adhesive Failure - Does not adhere to film	None	No change of color.	.0090"	.0048"

Longer term testing of the 7343/7139 urethane adhesive revealed that the material began to loose strength quite rapidly with time at a temperature of 350°F (177°C). For example, after about 50 hours at 350°F (177°C) the ambient temperature peel strength dropped off from about 4 lbf/in. (715 gms/cm) to about 1 lbf/in. (179 gms/cm). In addition, the adhesive began to darken in color indicating the possibility of a chemical change in the material. A silicone additive was combined with the Crest 7343/7139 urethane adhesive in an effort to decrease the degrading effect of the 350°F (177°C) environment. The additive, Dow Corning Z6040, was added to the urethane resin in a 1% by weight ratio prior to adding the catalyst. Resulting peel strength was 5.2 lbf/in. (929 gms/cm) and 5.5 lbf/in. (804 gms/cm) respectively for the unmodified adhesive. However, ambient temperature peel strength dropped to 0.8 lbf/in. (143 gms/cm) after 90 hours at 350°F (177°C) and the adhesive was again observed to be darkened. Ambient temperature peel strength tests run on the modified urethane adhesive after 96 hours at 300°F (149°C), indicated a 2.8 lbf/in. (500 gms/cm) peel strength. In view of these long term temperature problems with the 7343/7139, it was eliminated as a hot side adhesive candidate. Previous experience on earlier contracts (references 1-3) predict this adhesive would function quite adequately on the cold portion of the panels should a two adhesive system be selected, i.e. one for the hot region and another for the cold region.

Silicone adhesives in general have in the past shown excellent long term thermal stability at temperatures as high as 600°F (316°C). For example, Dow Corning suggests the maximum continuous service temperature for its 732 RTV is about 450°F (232°C) which is certainly adequate for this application. The main problem with the Dow Corning 732 RTV adhesive is with low temperature flexibility. Vendor literature suggests a minimum service limit of -80°F (-62°C). Screening tests were run on the 732 RTV to determine the effect of joint thickness on peel strength and flexibility when cold. Plain Kapton peel samples with varying thicknesses of adhesive were prepared and tested. Adhesive thickness ranged from 0.8 mil (0.2 mm) to 18 mil (0.46 mm). Testing consisted of bending prepared samples 180° around rods of 3/4 inch (1.9 cm) and 1/4 inch (.64 cm) diameter while at LN_2 temperature. The flex tests were of a subjective nature and involved visual inspection for cracking or delamination. Results indicate that peel strength reaches a maximum of approximately 12 lbf/in. (2145 gms/cm) at a thickness of about 10 mils (0.25 mm). However, beyond a thickness of 7 mils (0.178 mm) the adhesive becomes brittle at LN_2 temperature and will crack when bent over a 1/4 in. (0.64 cm) diameter rod. Samples soaked in water overnight prior to bonding (RTV adhesives cure by reaction with moisture) and allowed to dry 1 hour in room air, generally exhibited only marginally better peel strengths and bending characteristics than the untreated samples. The 12 lbf/in (2145 gms/cm) peel strength achieved with 732 RTV meets the criterion of 1/4 the tensile strength of the Kapton film. It appears therefore that an adhesive thickness of about 7 mils (0.18 mm) will provide adequate peel strength and flexibility for use with Kapton. The test results are summarized in Table 5.

TABLE 5

Effect of Adhesive Thickness on 732 RTV Flexibility and Strength

Adhesive Thickness Mil	Peel Strength, after LN_2 dip Lbf/in. Width	3/4" dia. bend at LN_2 Temperature	1/4" dia. bend at LN_2 Temperature	Remarks*
0.8	1.2	No Break	No Break	Plain
3.5	5	No Break	No Break	Plain
3.2	7.6	No Break	No Break	Soaked
5.0	6.5	No Break	No Break	Plain
5.5	10.2	No Break	Stiff, but will flex without break	Soaked
6.8	8.4	No Break	Stiff, but no break	Plain
7.0	11.1	No Break	Slight cracking near near edges	Soaked
11.5	12.5	Break	Very stiff - break	Plain
11.0	13.5	Break	Very stiff-- break	Soaked
13.3	13.2	Break	Very stiff - break	Plain
14.0	13.5	Break	Very stiff - break	Soaked

* - Soaked refers to Kapton samples soaked in H_2O overnight then dried and allowed to sit in room air for 1 hour before bonding.

- Plain refers to as received Kapton sample.

The remainder of the adhesive testing was performed with high temperature polyester and heat stabilized Nylon 6 materials. The criterion for peel strength was again set at 1/4 the tensile strength of the film. For Nylon, a strength of about 5 lbf/in (894 gms/cm) is required and for the polyester material about 10 lbf/in (1787 gms/cm).

Several types of adhesives were investigated. They included RTV, silicone, rubber based, solvent based and epoxy adhesives as well as heat sealing techniques.

Results of the adhesive peel strength tests are included in Tables 6 and 7. It can be seen in Table 6 that the RTV silicone adhesive supplied adequate strength for a polyester bond when cured at 350°F (177°C).

Additional tests were run with the RTV adhesive in an attempt to promote better adhesion with the Nylon materials. The adhesive was cured at higher temperatures, e.g. 350-425°F (177-318°C) with little improvement in peel strength. The casing material was soaked in water before bonding with similar results. Chemical "roughening" by treating the material surface with a chromic acid etch (a strong oxidizing agent) was tried but again peel strength was not appreciably increased. It appears therefore that the RTV adhesive/Nylon casing combination will not provide sufficient strength for this application.

The rubber based adhesives tested, although recommended by the manufacturers for applications in the 350°F (177°C) range, proved unsatisfactory at these temperatures. However, good adhesion was obtained with the rubber based adhesives at room temperature e.g. 3M's Scotch 1711 and the Nylon casings, and 3M's Scotch 1300 and the polyester materials (See Table 7). The epoxy adhesives tested, i.e. 3M's 2214 High Temperature and 2214 High Flex, were brittle and showed poor adhesion. The solvent based adhesive tested, Nylaweld (Polymer Corp.) seemed to weaken the Nylon film and caused casing failure. It did, however, show good strength and heavier gauge materials might allow use of this adhesive.

Several heat sealing techniques were also investigated for Nylon with varying degrees of success. The easiest and most successful method tried was a bead heat sealing method. The two layers of film to be welded were placed with their edges extending from between 2 metal jaws as in a vise. The edges extended approximately 1/8" (.318 cm) beyond the jaws but no more. This excess material was then heated with a hot wire or open flame so that the material melts forming a bead along the outer edge of the jaws. Joints made by this method are strong and difficult to separate. A small panel of 2 mil (0.05 mm) Capran (Nylon) was fabricated using this heat sealing method. A leak check showed the panel to be leak tight. The bead, however, was very brittle and was easily broken by small amounts of flexing at room temperature. In all of the heat sealing techniques tested, either the material immediately adjacent to the seal was weakened or the seal itself was brittle. For

TABLE 6

732 RTV Peel Test Results

Adhesive/ Manufacturer	Adhesive Thickness, in.	Casing[1] Material	Peel Strength * lbf/in.	Pre-Test Treatment[2]	Comments
732 RTV/Dow Corning	.003	Capran	0.1	23 Days room temperature cure	Bond fail
	.002	Capran	0.5	23 Days; 350°F. overnight	Bond fail
	.004	Capran	0.8	23 Days; 350°F.; LN_2 dip	Bond fail
	.006	Capran	0.1	23 Days room temperature cure; etched	Bond fail
	.005	Capran	2.1	23 Days; etched; 350°F. overnight	Bond fail
	.004	Capran	1.5	23 Days; etched; 350°F.; LN_2 dip	Bond fail
	.007	Reynolon	0.9	14 Days room temperature cure	Bond fail
	.005	Reynolon	2.8	14 Days; 350°F. overnight	Bond fail
	.004	Reynolon	0.8	14 Days; 350°F. overnight; LN_2 dip	Bond fail
	.013	Reynolon	1.1	14 Days room temperature cure; etched	Bond fail
	.007	Reynolon	1.9	14 Days; etched; 350°F. overnight	Bond fail
	.004	Reynolon	1.1	14 Days; etched; 350°F. overnight	Bond fail
	.009	Mylar	0.9	15 Days room temperature cure	Bond/adhesive fail
	.008	Mylar	>6.7	15 Days; 350°F. overnight	½ mil casing broke
	.009	Mylar	>6.7	15 Days; 350°F.; LN_2 dip	½ mil casing broke
	.011	Mylar	2.8	15 Days room temperature cure	Bond/adhesive fail
	.006	Mylar	6.3	15 Days; etched; 350°F. overnight	Adhesive fail
	.010	Mylar	>6.7	15 Days; etched; 350°F.; LN_2 dip	½ mil casing broke
	0.18	Celenar	2.8	17 Days room temperature cure	Adhesive/bond fail
	0.17	Celenar	12.7	17 Days; 350°F. overnight	Adhesive fail
	0.12	Celenar	12.0	17 Days; 350°F.; LN_2 dip	Adhesive fail
	0.12	Celenar	1.9	17 Days room temperature cure; etched	Adhesive/bond fail
	0.13	Celenar	8.5	17 Days; etched; 350°F. overnight	Adhesive fail
	0.10	Celenar	13.0	17 Days; etched; 350°F.; LN_2 dip	Adhesive fail

NOTES: 1. Material trade names: Capran - nylon - Allied Chemical; Reynolon - nylon - Reynolds Aluminum; Mylar - polyester - Dupont; Celenar - polyester - Celenese Plastics.

2. Etched: surface roughened with No. 500 emery paper.

* All tests run at room temperature after 350°F exposure.

TABLE 7

ADHESIVE PEEL TEST DATA

Adhesive Manufacturer	Adhesive Thickness, In.	Casing Material (1)	Peel Strength, lbf/in.	Pretest Treatment	Comments
Scotch 1300/3M	.002	Celenar	4.0	R.T. Cure for 11 days	Adhesive failure.
Scotch 1300/3M	.003	Celenar	-	R.T. cure for 11 days followed by 350°F over-night soak	Adhesive darkened to charcoal color; material & casing in contact with it became very brittle; rest of casing re-mained flexible.
Scotch 1711/3M	.019	Capran	5.7	R.T. cure for 23 days	Adhesive tends to bubble and warp plastic film.
Scotch 1711/3M	.024	Capran	-	R.T. cure for 23 days followed by 350°F soak overnight	Adhesive darkened to charcoal color; material & casing in contact with it became very brittle; rest of casing re-mained flexible.
2214 HF/3M	.009	Reynolon	-	Cure as per manufacturers directions	No adhesion very stiff & brittle.
2214 HT/3M	.006	Mylar	-	Cure as per manufacturers directions	Very stiff & brittle no adhesion
Nylaweld	.001	Capran	15.0	Cure as per manufacturers directions	Casing material tears at edge of adhesive seam; seems to weaken plastic film.

(1) Material Trade Names - Celenar - Polyester - Celenese plastics; Capran - Nylon - Allied Chemicals; Reynolon - Nylon Reynolds Aluminum; Mylar - Polyester - DuPont

these reasons heat sealing seems to have little to offer as a means of sealing the SEMI panels. It is the conclusion of these adhesive tests that the best adhesive tested for our application is the 732 RTV used in conjunction with the polyester casing material.

4.2.1.3 Radiation Shield Tests

Samples of double aluminized Kapton shielding were sent to Grumman Aerospace for emittance testing. Three samples were sent in all; No. 1 - as received from the initial evaluation order, No. 2 - as received from the production order purchased for this contract, and No. 3 - from the production order that had undergone 115 thermal cycles in high temperature cycling test panel No. 2. Emittance tests were performed at nominal temperatures of 100°F (38°C) and 350°F (177°C). The data is presented in Table 8.

4.2.1.4 Spacer Tests

The objective of the spacer tests was to find light weight insulating materials which could function as multilayer insulation spacers at high and low temperatures with a minimum of damage due to temperature or mechanical cycling effects.

Open-cell polyurethane foam was sliced to a thickness of 0.02 - 0.024 inches (.51 - .61 mm), and used for the cold region spacer material. Previous experience showed the material acceptable for spacers up to a temperature of about 100°F (38°C).

Hot region spacer materials examined included Dexiglas mat and high temperature foam. The foam, Zer-O-cell Blue, a 2 pcf (0.032 gms/cm^3) closed cell polyurethane foam produced by the National Gypsum Company was reported to be functional from -423°F (-253°C) to +350°F (+177°C). A sample of the material was placed in a 300°F (149°C) forced air oven for about 60 hours and showed about a 4% weight loss, a 2% length loss and a 7% thickness loss. Another sample was placed under a 15 psi (103, 422 N/m^2) load for 3 hours at 300°F (149°C) and showed a 60% permanent reduction in thickness after removal of the load. A small panel (approx. 10" x 10") (25 cm x 25 cm) was built using the blue foam as the spacer material, and pressure cycled at 300°F (149°C) for about 100 hours. Post test examination of the foam showed the foam layers had been compressed and had actually fused to themselves and the radiation shielding. Results from these tests indicate this foam material is unacceptable as a high temperature spacer material. The Dexiglas on the other hand, was relatively unchanged by the temperature exposure and showed only a 10-15% thickness reduction after cycling. The Dexiglas material was selected as the hot region spacer material.

4.2.1.5 Offgassing Tests

In order to insure the self-evacuating capability of the insulation panels when installed on cryogenic tankage, the offgassing

TABLE 8

DOUBLE ALUMINIZED KAPTON EMITTANCE*

SAMPLE	TEMPERATIRE (°F.)	TOTAL HEMISPHERICAL EMITTANCE (ε TH)
1	109	0.037
	356	0.044
2	111	0.037
	257	0.043
3	102	0.039
	347	0.044

Reference A: The Development and Test of a Low to Moderately High Temperature Emissometer; by J. G. Androulakis, Progress in Astronautics and Aeronautics Vol. 20, 1967.

* Testing By Grumman Aerospace Corporation

characteristics of the various materials used in the insulation system must be known. These gases, if not condensible, could be a major limitation on the vacuum level obtainable in a panel. Fortunately, only helium gas and hydrogen gas will be of concern since the residual oxygen, nitrogen, etc., will have low vapor pressures at LH_2 temperature. In addition a H_2 getter can be included in the final design to reduce Hydrogen pressure.

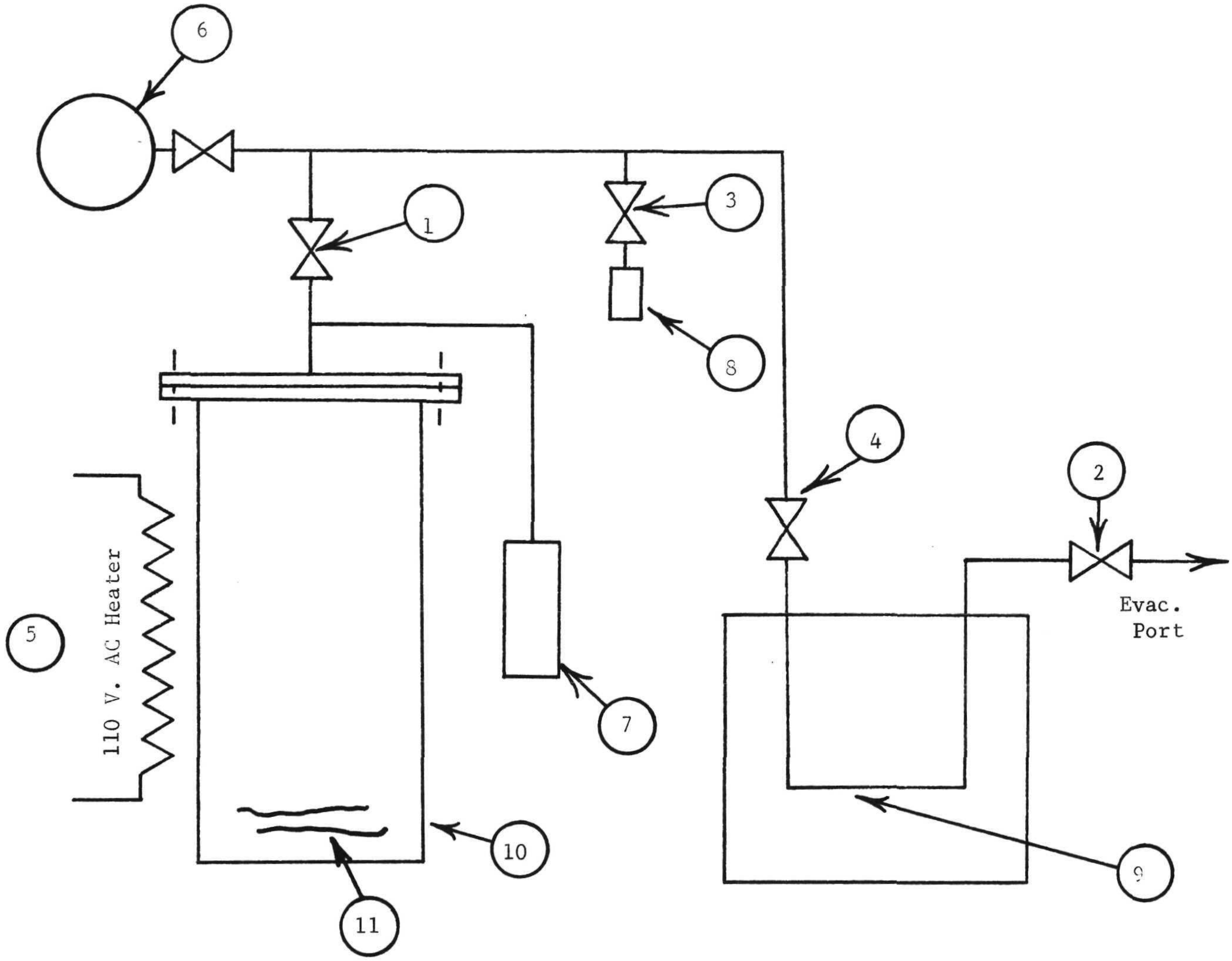
Materials tested for offgassing included the hot region radiation shield (double aluminized Kapton), the hot region spacer material (Dexiglas), and a combined sample of 1 mil (.025 mm) plain Kapton casing and Dow Corning 732 RTV adhesive. The cold region spacer (polyurethane foam) and cold region radiation shield (aluminized Mylar) and outer casing (Mylar polyester) were not tested as they were determined to be satisfactory under previous contracts (e.g. NAS 3-6289, Reference 1).

The general test procedure was as follows: Initially, the empty vacuum chamber was evacuated and leak checked. A pressure rise test was then conducted on the empty chamber at +350°F (177°C) to determine the chamber offgassing characteristics. The chamber was next re-pressurized using dry N_2, the material to be tested was inserted, and pump-down of the system begun. (White gloves were worn when handling the material to avoid sample contamination by direct skin contact). The sample was allowed to pump overnight at ambient temperature. The chamber was then valved off by closing valve No. 1 (see Figure 7). The heater was turned on and the temperature held at 350°F (177°C) until the pressure in the test chamber stabilized. With valves to the hydrogen getter, sample bottles, and valve No. 2 and No. 4 closed, valve No. 1 was opened, allowing the hot test gas to expand into the rest of the system. After the pressure settled out, valve No. 4 was opened exposing the gas to the LN_2 trap. After pressure settle-out, the H_2 getter was opened to the system. The residual gas then remaining in the system was considered as non-condensible in the panels.

Results from the aluminized Kapton offgassing test showed a small residual pressure of about 0.1μHg with the LN_2 trap and H_2 getter opened to the system. This pressure is roughly the same as the residual pressure of the empty chamber, and suggests no offgassing problems with Kapton. Mylar polyester material offgassing tests were run on previous contracts, but at lower temperatures. However, no new additional non-condensible gases are expected from the material at this increased temperature. We therefore conclude from these test results and results of previous work that no offgassing problem should exist with the system casing material. Furthermore, should a small quantity of non-condensible gas be evolved, it would not be considered a serious problem since it was shown in previous contracts that due to limited panel conductance, a panel pressure below 1μHg is not achievable in a reasonable length of time. Since the purpose of this test was then to demonstrate that a large volume of non-condensible gas would not be generated by the panel constitutes, no attempt is made to accurately analyze the gasses given off.

FIGURE 7

SCHEMATIC OFFGASSING APPARATUS



1, 2, 3. 4	Vacuum Valves
5	Temperature Controller and readout
6	Sample bulb
7	Equibar Pressure Readout
8	Hydrogen getter
9	LN_2 cold trap
10	Test chamber - Vol. = 0.56 ft^3, 6½" Dia.
11	Test sample

Similar results were obtained for tests run on the Dexiglas spacer and casing/adhesive combination.

4.2.2 System Screening Tests

4.2.2.1 High Temperature Tests

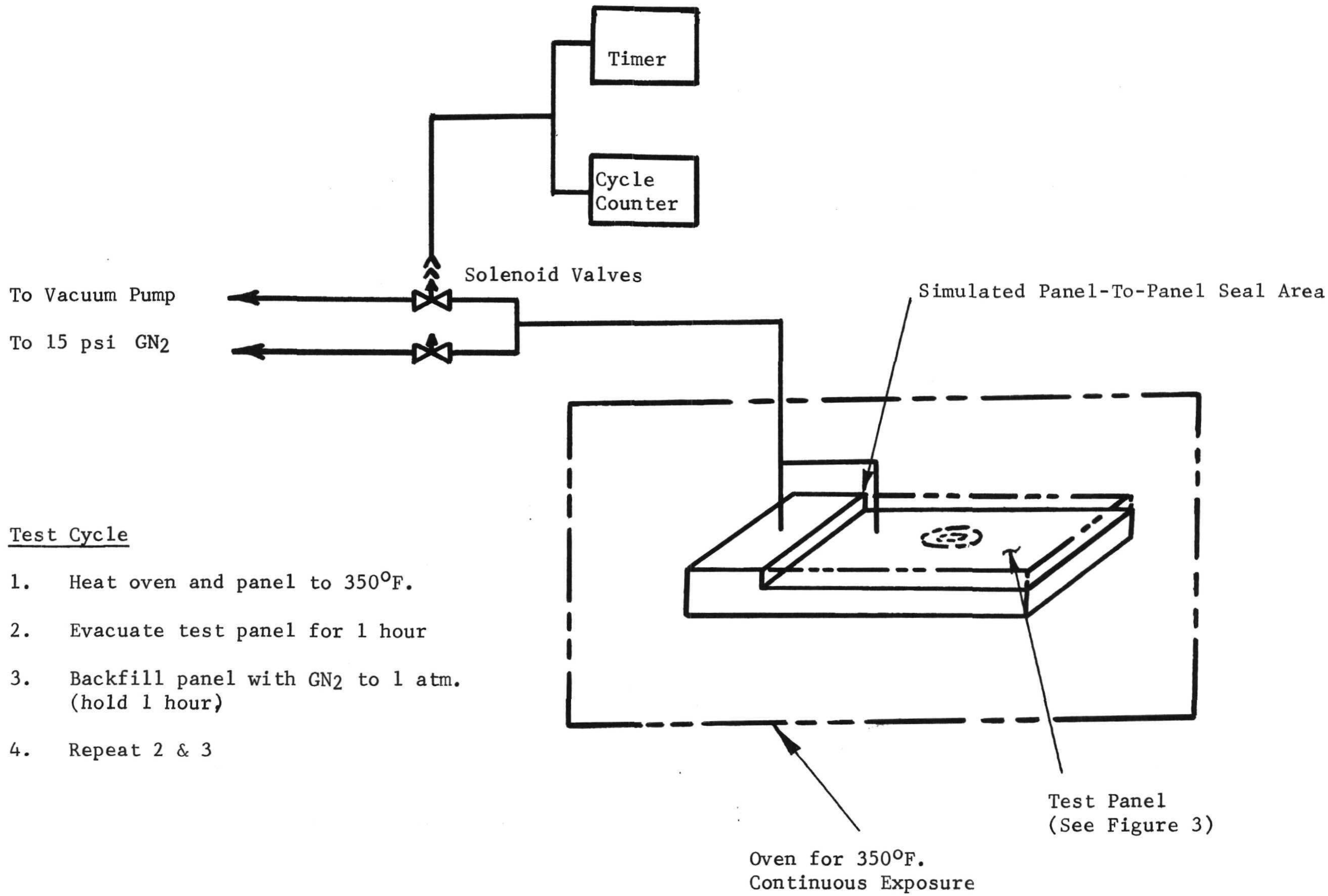
The purpose of these screening tests was to determine if the candidate materials selected for use in the hot region of the SEMI panels could withstand exposure to a high temperature environment for a time equivalent to that accumulated during 100 missions. Initial testing was done at 350°F (177°C) with Kapton laminate casing materials while subsequent tests used a single layer casing material (Kapton or polyester) and a 300°F (149°C) temperature limit. By cycling internal panel pressure, mechanical flexing of the small vacuum test panels (12" x 18", 30.5 cm x 45.7 cm) was achieved while at temperature. Post-test panel leak rates and material properties such as adhesive peel strength, radiation shield emissivity, spacer thickness, etc. were then compared to pre-test values.

It is estimated that the hot region of the SEMI panel will be exposed to a high temperature environment for approximately 2 hours following re-entry on each of the 100 missions. The small test panels were therefore exposed to the high temperature environment for a total of 200 hours. At 1 hour intervals, the panels were alternately evacuated, then backfilled with Coleman grade CO_2 to simulate flexing of the materials which will occur when the materials are in the hot condition.

The high temperature cycling apparatus consisted of three basic components - a vacuum pump and valve, a carbon dioxide source and valve, and a test panel (see Figure 8). The two hour test cycle consisted of a vacuum cycle (1 hr) during which the panel and fixture are evacuated, and a pressure cycle (1 hr) in which the fixture and panel are pressurized to one atmosphere with carbon dioxide.

Initial testing was done using casing laminates made from 2 and 4 layers of metallized Kapton. Laminates were supplied by National Metallizing Corporation and consisted of single aluminized layers of 0.5 mil (.0127 mm) Kapton on the outer most layers and double aluminized 0.5 mil (.0127 mm) for the inner two layers of the 4 ply casing. Layers were laminated by National Metallizing with a proprietary pressure sensitive adhesive. All Kapton testing was carried out at 350°F (177°C).

The first test panel was built using a 2-ply Kapton laminate casing. Inside were 4 double aluminized 0.5 mil (.0127 mm) radiation shields and 5 layers of 0.125 in (.318 cm) thick Dexiglas mat spacers. In addition a layer of .1875 in (.476 cm) thick honeycomb (type HRH-10 3/16 - 2.0, Hexcel Corp.) was included as the outer most layer on one side of the panel. Crest 7343/7139 urethane adhesive was used to bond the casing joints. Dow Corning 280A silicone pressure sensitive adhesive was used for part of the panel-to-panel seals as was Dow Corning 732 RTV silicone adhesive



Test Cycle

1. Heat oven and panel to 350°F.
2. Evacuate test panel for 1 hour
3. Backfill panel with GN_2 to 1 atm. (hold 1 hour)
4. Repeat 2 & 3

Figure 8

High Temperature System Mechanical Cycling Test

and Matcote Poly R S-944 (a 2-part Butyl rubber) (See Figure 9). Testing was performed for 2 hour cycles at 350°F (177°C) as follows: during the first 60 minutes, the panel was maintained at 1 atmosphere pressure of CO_2. At the conclusion of this first hour, the panel was evacuated and subjected to atmospheric pressure. This process was repeated a minimum of 100 times. During the entire 2 hour cycle, the panel and fixture were maintained at 350°F (177°C). At the conclusion of the first test (130 cycles) several observations were made. The urethane adhesive had turned very black and in most areas had a sticky tar-like appearance, and its peel strength was very low. (See Table 9). The 280A silicone adhesive remained tacky, but had a tendency to creep under load, leaving void areas and other areas of adhesive build-up. Consequently, it did not seal effectively. The Dow Corning 732 RTV silicone adhesive withstood all cycling and remained intact, exhibiting an unchanged peel strength of 12 lbf/in. (2145 gms/cm). At 350°F (177°C) the VELCRO fastener darkened and became quite brittle although its peel strength was unchanged (approx. 1 lbf/in., 179 gms/cm). (In actual service the VELCRO will never see these elevated temperatures). The Matcote 2 part butyl rubber used as a panel-to-panel seal became very brittle and powdery after about 50 cycles. The honeycomb used in the panel had about 7% weight loss after the test, and the dexiglas spacer material underwent about a 10% thickness reduction. Casing helium permeation (using 0.1% He in Ni mixture) rose from 2.5×10^{-5} atm-cm^3/sec-ft^2 (0.232×10^{-5} atm-cm^3/sec-m^2) to 3.1×10^{-5} atm-cm^3/sec-ft^2 (0.288×10^{-5} atm-cm^3/sec-m^2) after testing. From these observations, several conclusions were made; first, the urethane adhesive is not adequate for long term 350°F (177°C) service. Secondly, the 280A silicone pressure sensitive adhesive and the Matcote coating will not provide a satisfactory panel-to-panel seal system. The silicone adhesive provides a panel-to-panel seal capability, and should be used on all subsequent panels.

A second test panel was fabricated from 4 ply Kapton laminate casing material and contained 4 layers of double aluminized 0.5 mil (.0127 mm) Kapton radiation shields and 5 layers of 0.125 in (.318 cm) spacers. Crest 7343/7139 urethane adhesive with 1% by weight Dow Corning silicone additive Z6040 was used in the panel construction. Dow Corning 732 RTV silicone adhesive was used for all panel-to-panel seals. At the conclusion of 115 cycles, the panel and fixture were removed from the oven. The modified urethane adhesive was observed to have darkened, but was not sticky as in the first panel, and peel strength after testing was higher than after the first test (see Table 9). The RTV in the panel-to-panel seals functioned adequately with a reduced peel strength of about 6 lbf/in (1072 gms/cm) which was probably due to incomplete adhesive cure (indicated by acetic acid odor after testing). A problem was noted, however, with the 4 ply casing laminating adhesive. In some areas the casing layers had "slid" on each other as much as 1/4" (6.3 mm). Peel tests indicated a laminate adhesive peel strength of only 0.5 lbf/in. (89 gms/cm) after the test (0.7 lbf/in (125 gms/cm) prior to test). Casing permeation rate remained about the same after the cycling, i.e. about 2.5×10^{-5} atm(cc)/sec-ft^2 (2.32×10^{-6} atm (cc)/sec-m^2).

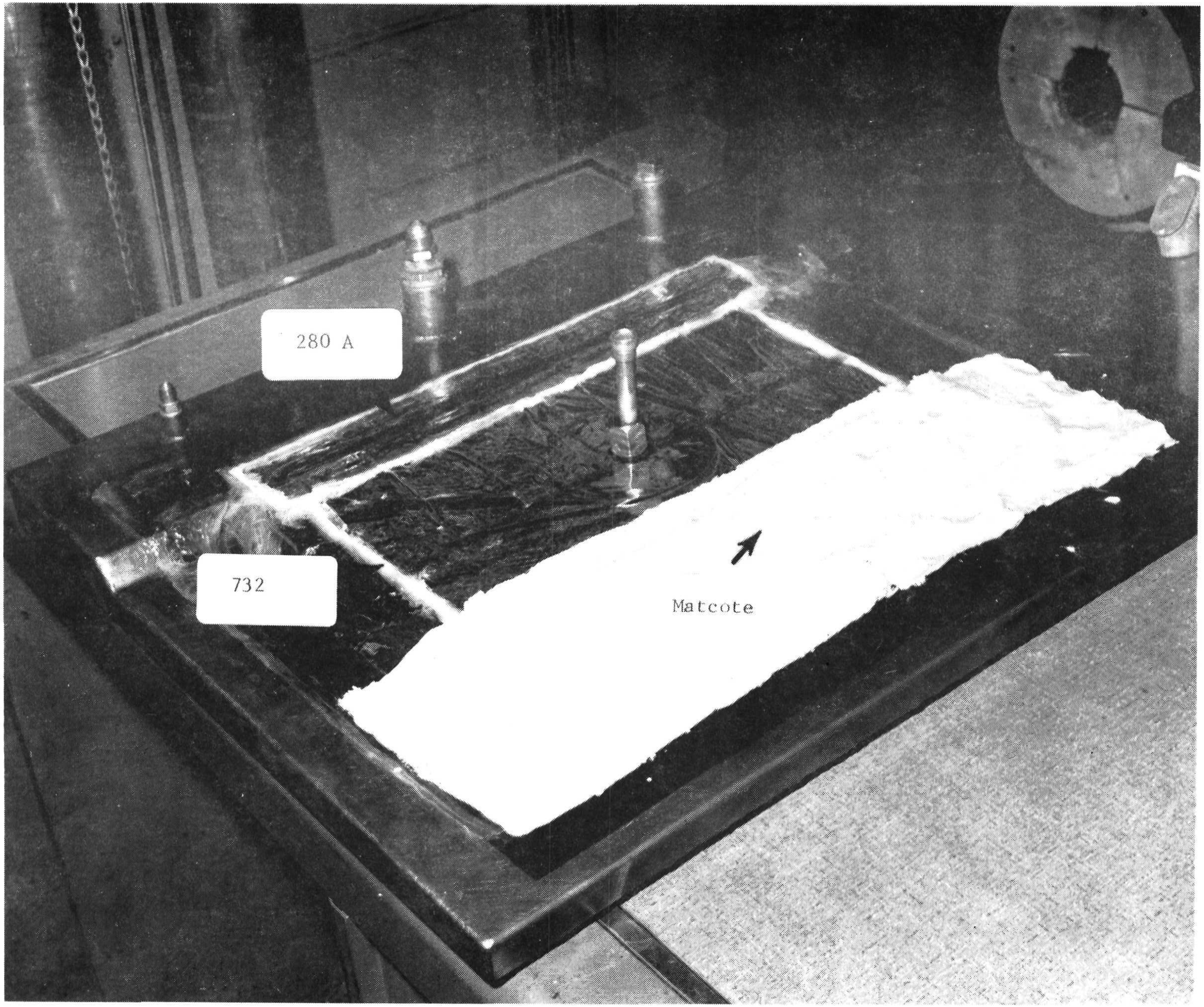


Figure 9 High Temperature Screening Test Panel Installed on Fixture Prior to Test

TABLE 9

HIGH TEMPERATURE CYCLING TEST PANEL ADHESIVE
PEEL STRENGTH DATA

Panel No.	Casing Material	Adhesive	Pre-test Peel Strength lbf/m	Post-test Peel Str. lbf/in.	Comments
1.	2 ply Kapton	Urethane	4.1	.2	Casing joint adhesive darkened and tar line
		732 RTV	12.0	12.0	Panel-to-panel seal adhesive
2.	4 ply Kapton	Modified Urethane	4.2	1.5	Casing joint adhesive darkened but not sticky
		Laminate Adhesive	.7	.5	Layers had on each other
		732 RTV	6.0	6.0	Reduced peel strength probably due to lack of cure
3.	1 mil Kapton	732 RTV	11.5	12.0	Panel joints
		Temp-R-Tape Temp-R-Glass	1.1 1.1	1.6 1.3	Creep and delamination is a problem
		732 RTV	10.5	10.5	Panel-to-panel joints
4.	300 S Mylar	732 RTV	11.0	10.5	Casing joint adhesive
		732 RTV	12.0	12.5	Panel-to-panel adhesive

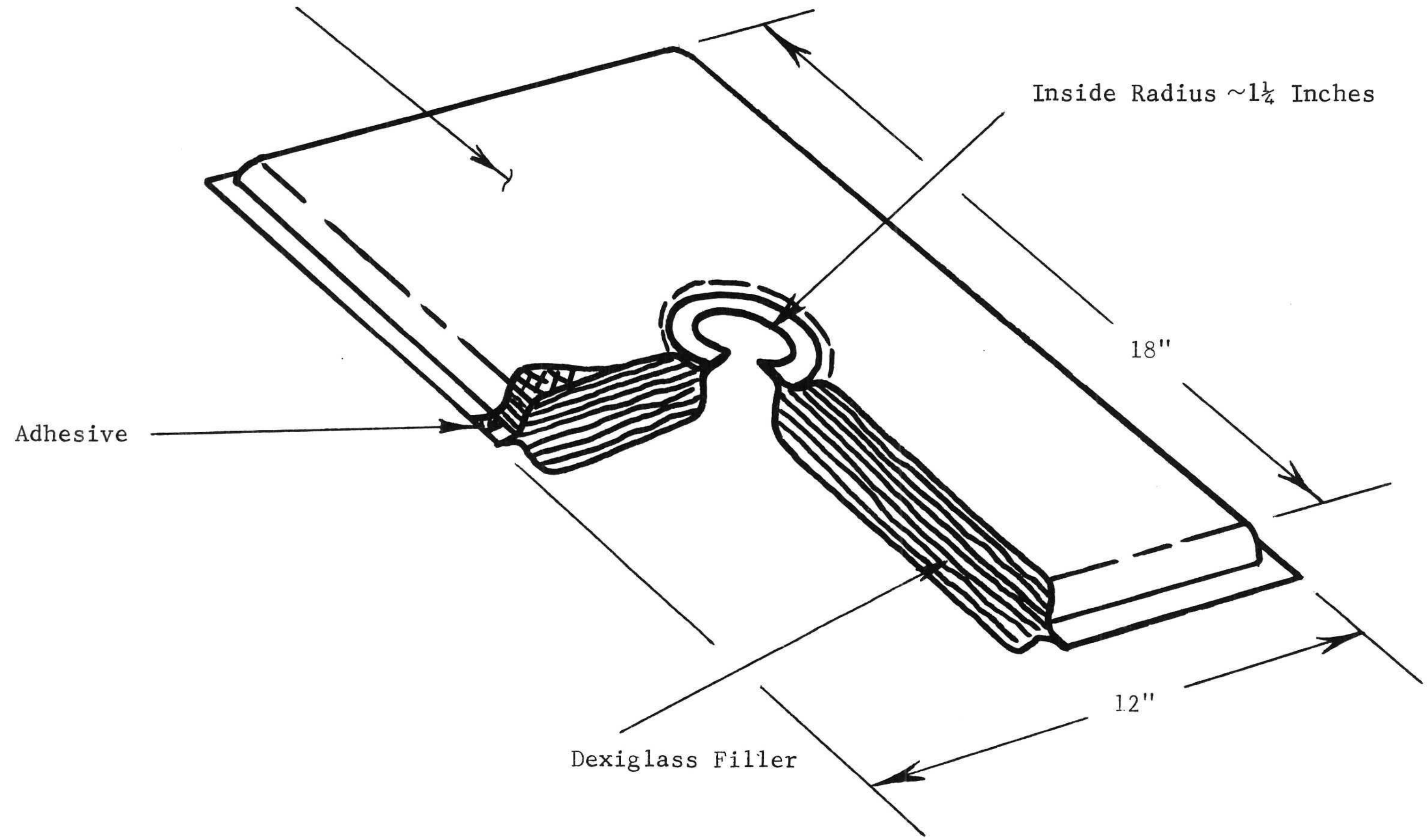
Several conclusions were drawn from these laminate panel test results. First, although the urethane adhesive with the silicone additive is a definite improvement over the plain urethane, it still does not provide sufficient strength. Second, although the RTV adhesive did not appear to be fully cured in the second panel (indicated by reduced peel strength), it does not appear to affect the ability of the adhesive to provide satisfactory panel-to-panel seals. It is considered the best candidate tested for panel-to-panel joints. The 4 ply laminate had some serious problems with layers sliding and with wrinkles in the material and is considered unsatisfactory as a casing material. Also the Dexiglas spacer material performs adequately under high temperature/mechanical cycling.

In view of the unacceptable performance of the Kapton laminate tested and the development of the single layer casing/manifolding concept, a second series of cycling tests was run using panels constructed from single layer casing materials. With the results of the Grumman thermal study predicting a maximum surface temperature of 150°F (66°C) in mind, the test temperature for these tests was reduced from 350°F (177°C) to 300°F (149°C). This temperature reduction allowed examination of a new material i.e. polyester in addition to Kapton as single layer casing material candidates.

Test panels approximately 12 inches x 18 inches (25 cm x 46cm) were constructed as in previous tests. These panels also included a simulated penetration area (See Figure 10). Previous handling tests suggested the small inside radius in such a penetration area could cause handling problems. Panels were placed on the high temperature test apparatus (see Figure 8) and pressure cycled between vacuum and one atmosphere as on previous tests. At the completion of testing, the panels were again leak checked and panel-to-panel seals evaluated. The panels were then cut open and casing permeation compared to pre-test values. The strength acceptance criteria was that there be essentially no change in tensile or tear strength or adhesive peel strength of the casing.

A third high temperature cycling test panel was built using plain 1 mil (.025 mm) non-metallized Kapton as the casing material and contained 5 layers of Dexiglas mat filler. Dow Corning 732 RTV silicone adhesive was used for all panel and panel-to-panel seals. In addition, samples of type TH Temp-R-Tape and A2012 Temp-R-Glass (Connecticut Hard Rubber Co.) were included on the panel for cyclic evaluations as panel-to-panel seal materials. Temp-R-Tape (Type TH) is a plain teflon material backed with a pressure sensitive silicone adhesive. Temp-R-Glass (Type A2012) is a teflon coated glass fabric backed with a similar adhesive. These materials were considered for use as panel-to-panel seal materials since they can withstand 400°F (204°C) and are easy to install. The Kapton panel was tested for 107 cycles.

Post test analysis revealed the Temp-R-Tape material (adhesive backed Teflon) started to curl around the edges as the adhesive released. The adhesive would retack, however. The reinforced Temp-R-Glass did not curl at the edges during the test, but some cyclic wear was observed following



<u>Figure</u> 10

High Temperature Cycling Panel

manual flexing. Panel permeability remained relatively unchanged at about 1.7 x 10^{-3} atm-cc/sec-ft^2 (1.58 x 10^{-4} atm-cc/sec-m^2). The RTV joint adhesive retained its strength and flexibility at the conclusion of testing.

The results of this test suggest use of the 732 RTV as the panel adhesive for future work. It retained its peel strength and flexibility in the high temperature environment and as the adhesive tests suggest, remains flexible at low temperatures if the joint is sufficiently thin. The Temp-R-Glass and Temp-R-Tape materials although surviving the cycling tests, are not considered to be good panel-to-panel seal candidates as the adhesive system provides a questionable seal.

A fourth high temperature cycling test panel was fabricated from 3 mil (.076 mm) Mylar type 300 S polyester material and contained 5 layers of .125 in (318 cm) thick Dexiglas mat as filler. Dow Corning 732 RTV was used for all panel and panel-to-panel joints. Panel casing joints were cured overnight at room temperature under a 5 psi (34,474 N/m^2) bonding pressure followed by a one hour soak at 250°F (121°C). Nylon mesh was placed in all joint areas to determine its effect on joint efficiency during cycling. (Mesh in the joint area is a possible solution to casing tearing problems.) Casings were vacuum formed using a wooden female mold and heat gun. The center penetration area was formed separately on a metal mold in an oven at 400°F (204°C) and then bonded to the casing. Figure 11 shows the formed casing with penetration area and evacuation manifold in place. The finished panel is shown in Figure 12. The panel was then put on the high temperature cycling test fixture (Figure 13) and pressure cycled for 200 hours at +300°F (149°C). The pre and post-test leak rates remained about 8.1 x 10^{-3} atm cc/sec-ft^2 (7.52 x 10^{-4} atm-cc/sec-m^2). The casing remained flexible with no apparent color change. Panel-to-panel seals again remained tight and retained their strength (see Table 9).

Several conclusions were drawn from these four high temperature cycling tests. First, for 350°F (177°C) temperature requirements, the Kapton/RTV system is the only system tested capable of operating for the required time period. However, since the temperature requirements suggested by the Grumman study indicate much lower operating temperatures, a 300°F (149°C) upper limit is realistic. Lowering the limit by 50 degrees, allows use of the 300 S Mylar polyester/RTV system which has adequate long term (200 hours) aging characteristics, and forming characteristics superior to those of Kapton. Second, all panel-to-panel seals should be made using 732 RTV adhesive. This adhesive is simple to use, is a gap filling thixotropic (non-sagging) paste, and cures at room temperature providing adequate bond strengths capable of withstanding the 300°F (149°C) environment for the required 200 hours. Third, the Dexiglas spacer material has adequate long term (200 hours) temperature stability as do the double aluminized Kapton radiation shields.

4.2.2.2 Low Temperature Tests

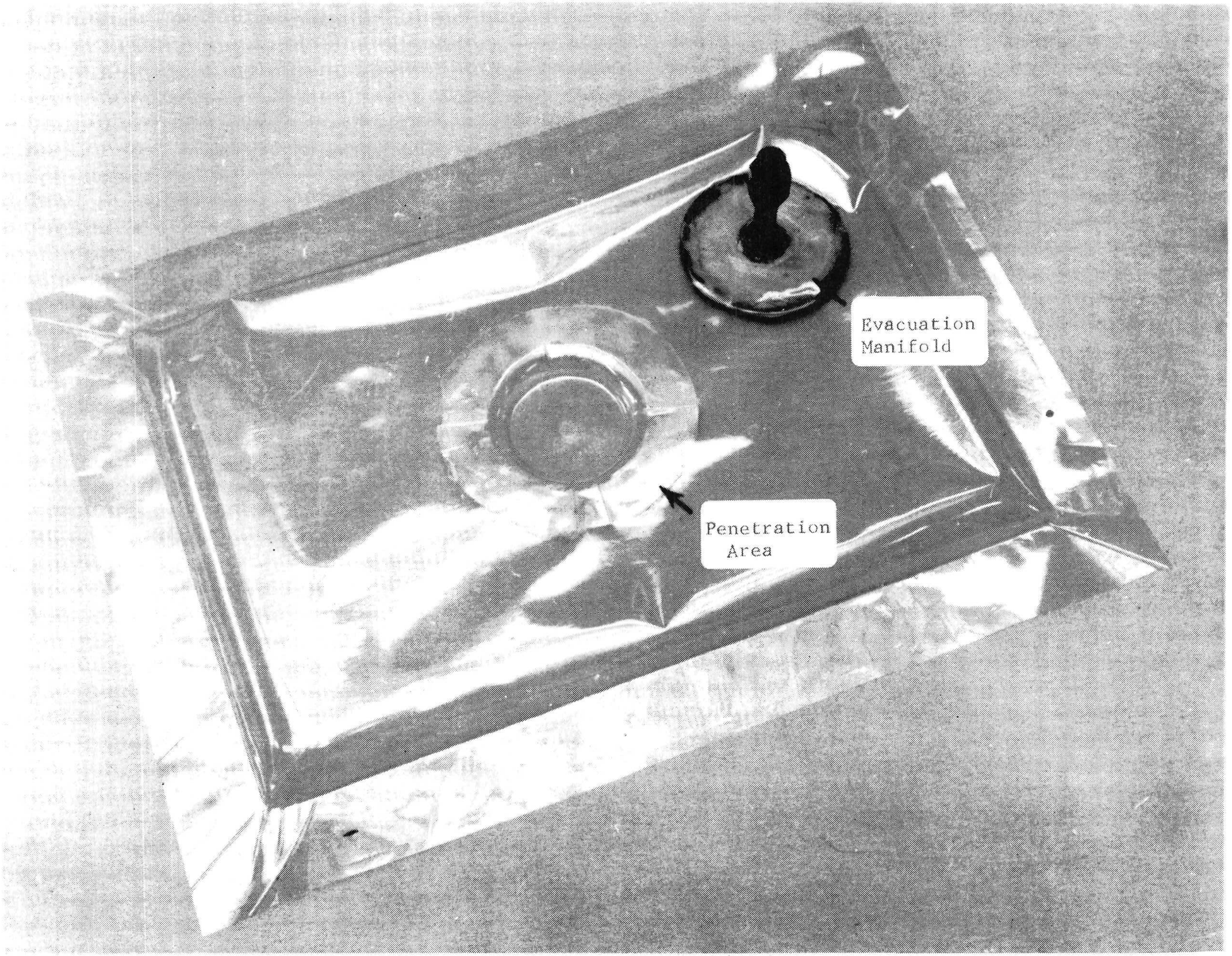


Figure 11 - Formed Polyester Casing For High Temperature Cycling Panel

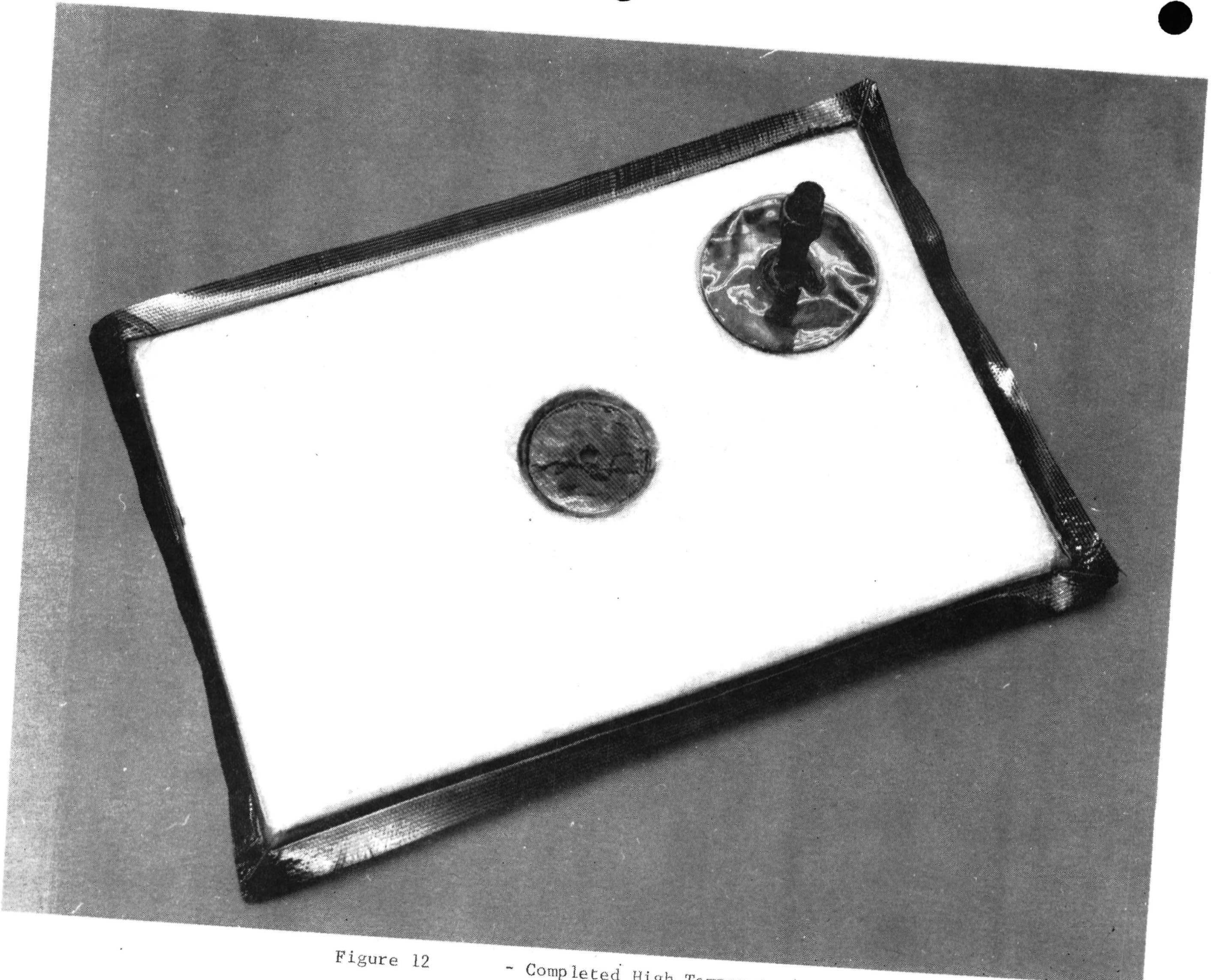


Figure 12 - Completed High Temperature Cycling Panel

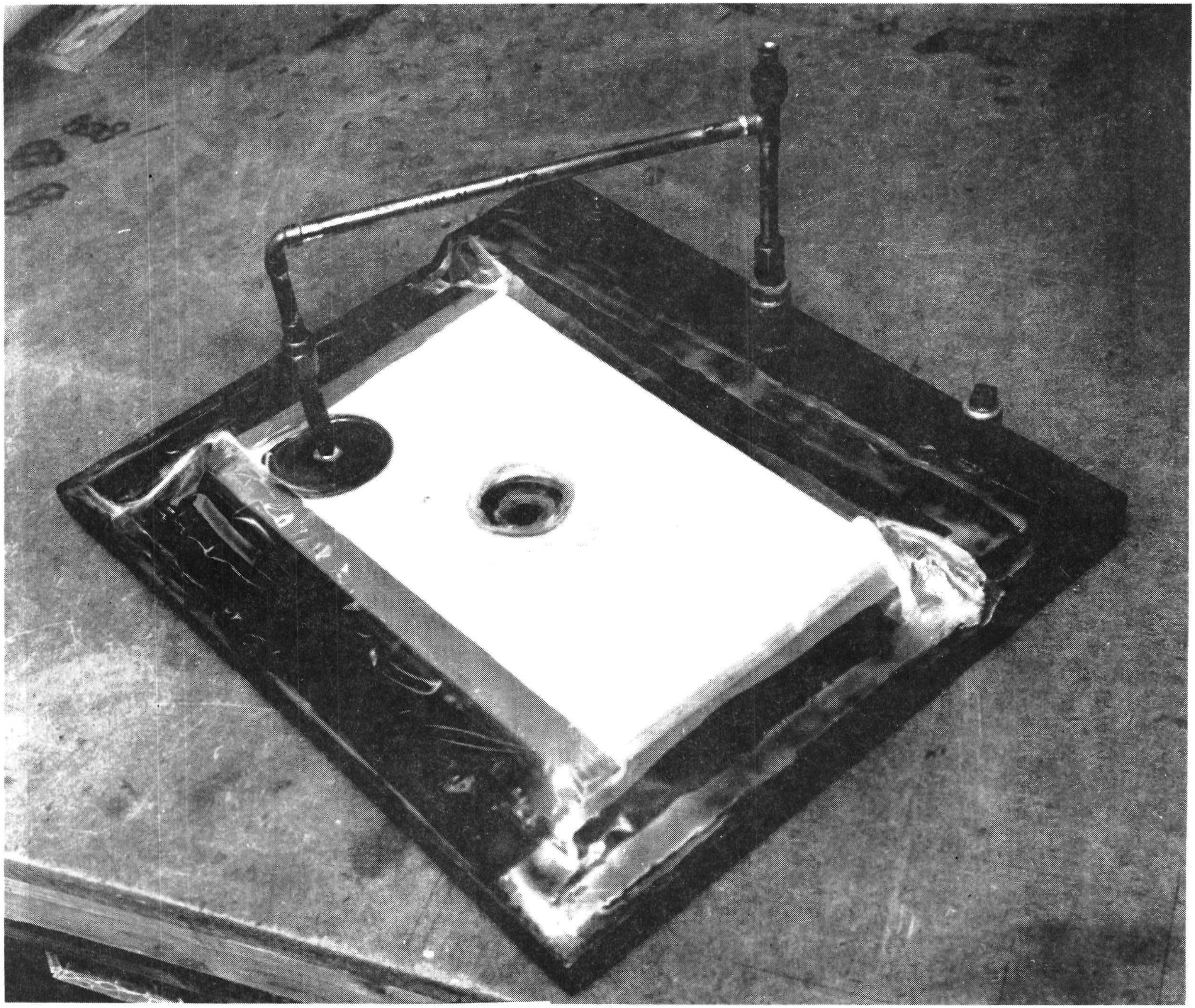


Figure 13 - Polyester Panel On High Temperature Cycling Fixture

4.2.2.2.1 Cryopumping Tests

Work performed under previous NASA contracts, i.e. NAS 3-6289, NAS 3-7953 and NAS 3-12045 (references 1-3) indicated that the gas conductance through the SEMI panels is quite low, thus, limiting the evacuation and cryopumping capabilities of the SEMI panel. Under contract NAS 3-7953, Linde briefly investigated the use of a pierced Hexcel Mylar honeycomb material for use as a conductance improvement layer. Under this contract, Linde again briefly investigated the use of honeycomb material, in this case a 3/16" (4.76 mm) thick Nylon-phenolic material. Testing consisted of monitoring pressure decay in panels cooled to LN_2 temperature.

The first panel to be used for the conductance improvement tests consisted of 5 composite layers of polyurethane foam spacers, 4 double aluminized Mylar radiation shields and a casing made of four-ply aluminized Mylar. Crest 7343/7139 adhesive was used throughout the panel. After evacuation and leak checking, the panel was backfilled with Coleman Grade CO_2 to a pressure of one atmosphere. The panel was then dipped into an LN_2 dewar to a depth of 7" (17.8 cm) i.e. 1/3 panel length (see Figure 14) and the pressure decay curve determined (see Figure 15).

The second panel consisted of 5 composite layers of polyurethane foam spacers and 4 double aluminized Mylar radiation shields plus a honeycomb layer next to the outer casing. The pump-down curve for the panels shown in Figure 15 indicates a small improvement for the panel containing honeycomb over the original panel.

A third and final panel was built using the same shields and spacers as the previous two panels and a layer of honeycomb with each cell sliced about 1/3 its height. (See Figure 15). The pump-down curve for the sliced honeycomb indicates an unexpected poorer performance than either of the previous panels. A probable explanation for this discrepancy is the existance of a small leak somewhere in the panel.

No definite conclusion was drawn from this series of conductance tests regarding the use of a honeycomb conductance improvement layer.

4.2.2.2.2 Cryogenic Cycling Tests

The purpose of this test was to determine if the candidate materials could withstand 100 cycles from ambient to LN_2 temperature. It is considered acceptable to substitute LN_2 testing for LH_2 testing since the difference in absolute contractions between LN_2 temperature and LH_2 temperature is small. (Casing material properties remain essentially the same below about -100°F, -73°C). To perform this test, small panels (approx. 12" x 18", 30.5 cm x 45.7 cm) were fabricated from the candidate materials, evacuated, and backfilled with CO_2. The panels were then cycled between ambient and LN_2 temperature, providing compressive loadings on the shields and separators, and flexural loading on the casing. After test completion (100 cycles) panel components were inspected for gross material damage incurred by cycling.

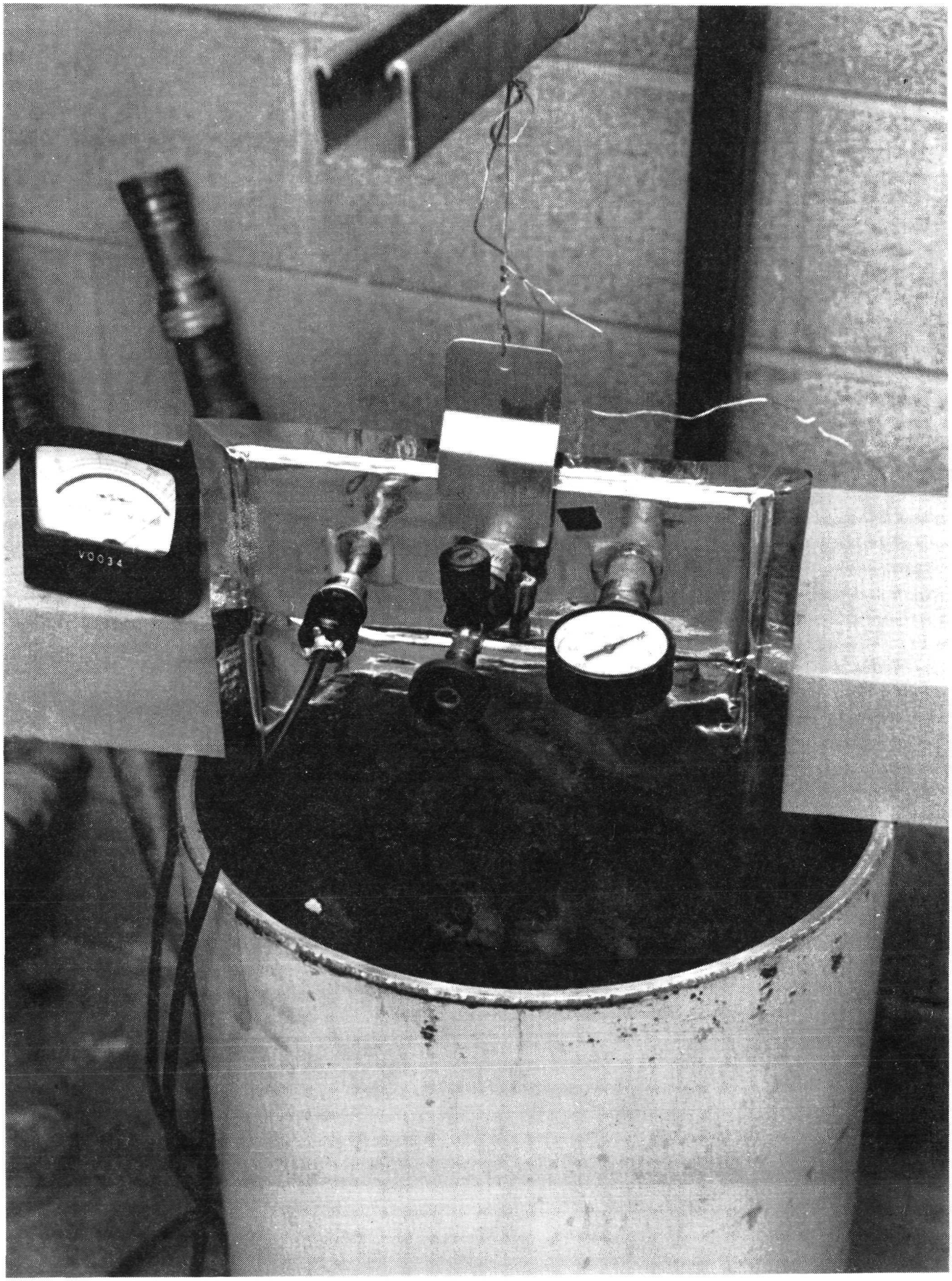


Figure 14
Panel Conductance Test

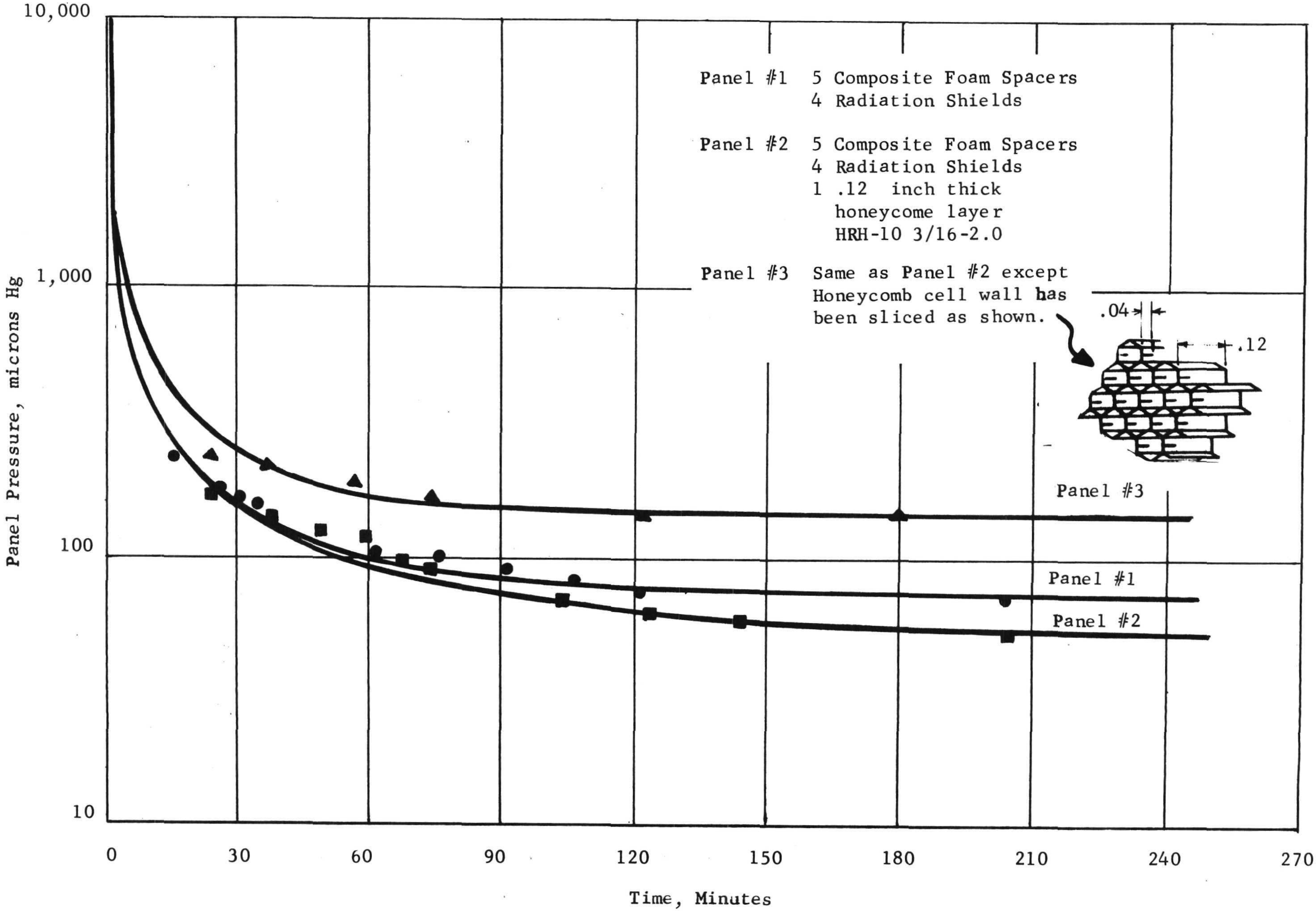


FIGURE 15 Conductance Panel Pressure Vs. Time (LN_2 Temperature)

The test apparatus consisted of an LN_2 supply and two valves controlling supply of LN_2 to two spray headers, one positioned on each side of the test panel. (See Figure 16). Spray sequence was controlled by a timer/ solenoid system. The headers allowed LN_2 to spray on both sides of the panel to cryopump the CO_2, which resulted in panel flexing. A centering frame was positioned between the two headers to restrain the panel and keep it centered between the two headers when flexed. Each 60 minute cycle consisted of 15 minutes of LN_2 spray, followed by a 45 minute warm-up to room temperature. To aid in this warming and to prevent line freezing during hold time, warm dry N_2 was blown through the headers.

The first test panel was fabricated from 4-ply Kapton laminate and contained 5 composite layers of sliced and punched polyurethane foam (see Figure 21) and 4 radiation shields of double aluminized Mylar. A layer of 3/16" (.376 cm) thick honeycomb material was placed between the last spacer and the panel casing. Crest 7343/7139 urethane adhesive modified with 1% by weight of Dow Corning Z6040 was used for all panel joints.

After completion of the cycling test, the panel was cut open for inspection. Tests showed that the panel adhesive joint remained flexible and exhibited a peel strength of about 1.5 lbf/in. (268 gms/cm). Peel strength for the laminate casing adhesive dropped from 0.7 lbf/in. (125 gms/cm) to about 0.5 lbf/in. (89 gms/cm). The casing showed many folds caused by the material being pressed against the honeycomb layer. The foam spacers were somewhat matted together although they easily peeled apart. The final thickness of the foam was about 0.019" (0.48 mm) or about 20% reduction in thickness due to cycling. Panel leak rate remained about 3.5×10^{-5} atm-cc/sec-ft^2 (3.25×10^{-6} atm-cc/sec-m^2).

A second panel was built with plain one mil (0.025 mm) nonmetallized Kapton film and contained 5 layers of punched and staggered foam and 4 double aluminized Mylar radiation shields as in the first panel. Panel joints were made with Dow Corning 732 RTV adhesive. Adhesive thickness averaged about 20 mil (0.51 mm). The panel was cycled 103 times. A gross leak check run before and after cycling showed a panel pressure rise of less than 1 in 10 minutes. Peel strength for the panel adhesive remained unchanged after testing at 12 lbf/in (2145 gms/cm). The foam spacers again were reduced in thickness about 20%. Some foam "dust" was noted although this is common in normal handling and is not considered to be a problem caused by the cycling.

Due to lack of program funds and time, the last of the cryogenic cycling tests was not run on the cycling apparatus previously described. Rather the panel was hand dipped into a dewar of LN_2 100 times, completely submerging the panel for 10-15 seconds each cycle. About 10-15 minutes was allowed between cycles to allow the panel to return to ambient temperature.

The third panel was built with 3 mil (.076 mm) type S Mylar polyester casing material and bonded with Dow Corning 732 RTV adhesive. Since the foam spacer and Mylar shielding had been qualified in previous

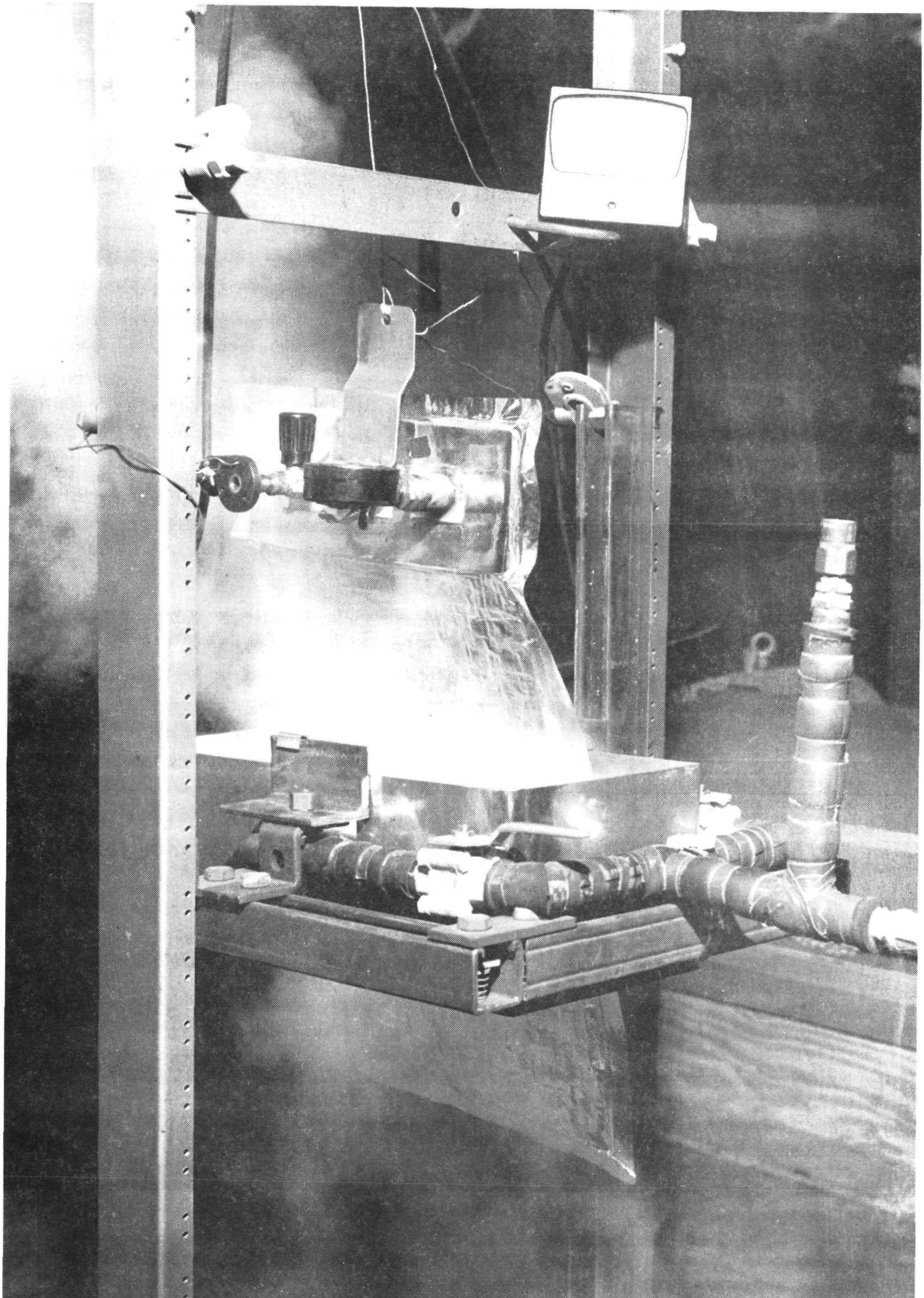


Figure 16
Cryogenic Cycling Test Apparatus

panels, this panel utilized 5 layers of Dexiglas material for a filler. This panel also incorporated a simulated panel penetration area similar to that in the high temperature polyester cycling panel. The third panel is shown in Figure 17.

At the conclusion of testing the panel was examined for damage incurred by cycling. Gross leak checks run before and after testing again indicated less than 1μ panel pressure rise in 10 minutes. The adhesive remained flexible as did the casing material.

Several conclusions can be drawn from these tests. First, the modified urethane adhesive although remaining flexible still exhibited a relatively low peel strength. This low peel strength along with higher temperature unsuitability, suggest it is unsatisfactory as a panel adhesive. The RTV adhesive, on the other hand, showed adequate performance when cold even though the joint was thicker than the critical thickness suggested by the adhesive tests (see Table 5). Second, the foam spacers showed little sign of break up due to cycling but did show about a 20% reduction in thickness. This thickness reduction is not expected to cause serious problems as it caused only small changes in system performance in previous work. The foam spacers therefore were chosen as the cold region spacer material. Third, the polyester/RTV system demonstrated it is capable of operating in a cold environment under mechanical cyclic conditions. This combined with its previously demonstrated 300^{o}F (149^{o}C) temperature capability suggest the use of the polyester/RTV system in future work.

4.3 Subscale Insulation System Testing (Task IV)

The space shuttle as currently conceived will be a multi-trip space vehicle. It must be able to withstand the environment of space as well as the atmospheric environment during lift-off, and re-entry. The liquid hydrogen tank insulation system, for example, must withstand a wide range of temperatures, from cryogenic on the inner panel surface to perhaps 300^{o}F (149^{o}C) on the outside panel surface. The insulation panels are expected to withstand the thermal exposure of 300^{o}F (149^{o}C) environment in addition to mechanical cycling due to internal and external pressure changes caused by cryopumping and atmospheric pressure variations during flight.

A combined pressure and thermal cycling test was performed on a 3-panel insulation system installed on a test vessel having both a spherical surface (simulating a portion of a tank head) and a cylindrical surface (simulating a portion of a tank section) (see Figure 18). In addition, a protrusion (simulated support rod, fluid line, etc.) was designed into each surface to allow evaluation of the insulation system around such an area. Two types of penetrations were investigated, i.e. a rigid type penetration and a semi-rigid type penetration (see Figure 19). Testing was performed in a vacuum chamber while the test vessel contained LN_2.

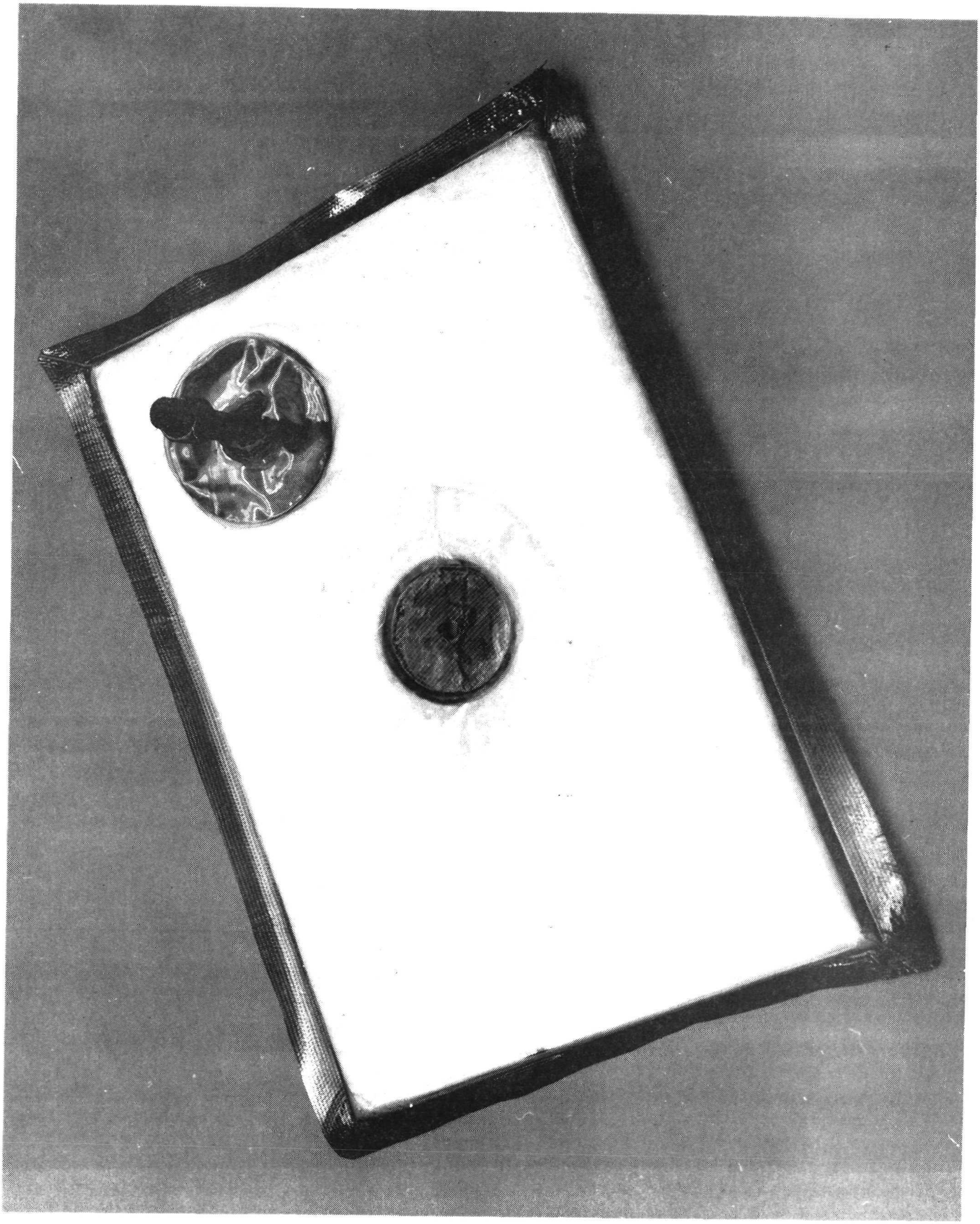


Figure 17 Polyester/RTV Cryogenic Cycling Panel

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

U/M	ITEM NO.	PART OR CODE NO.		MATERIAL AND DESCRIPTION		

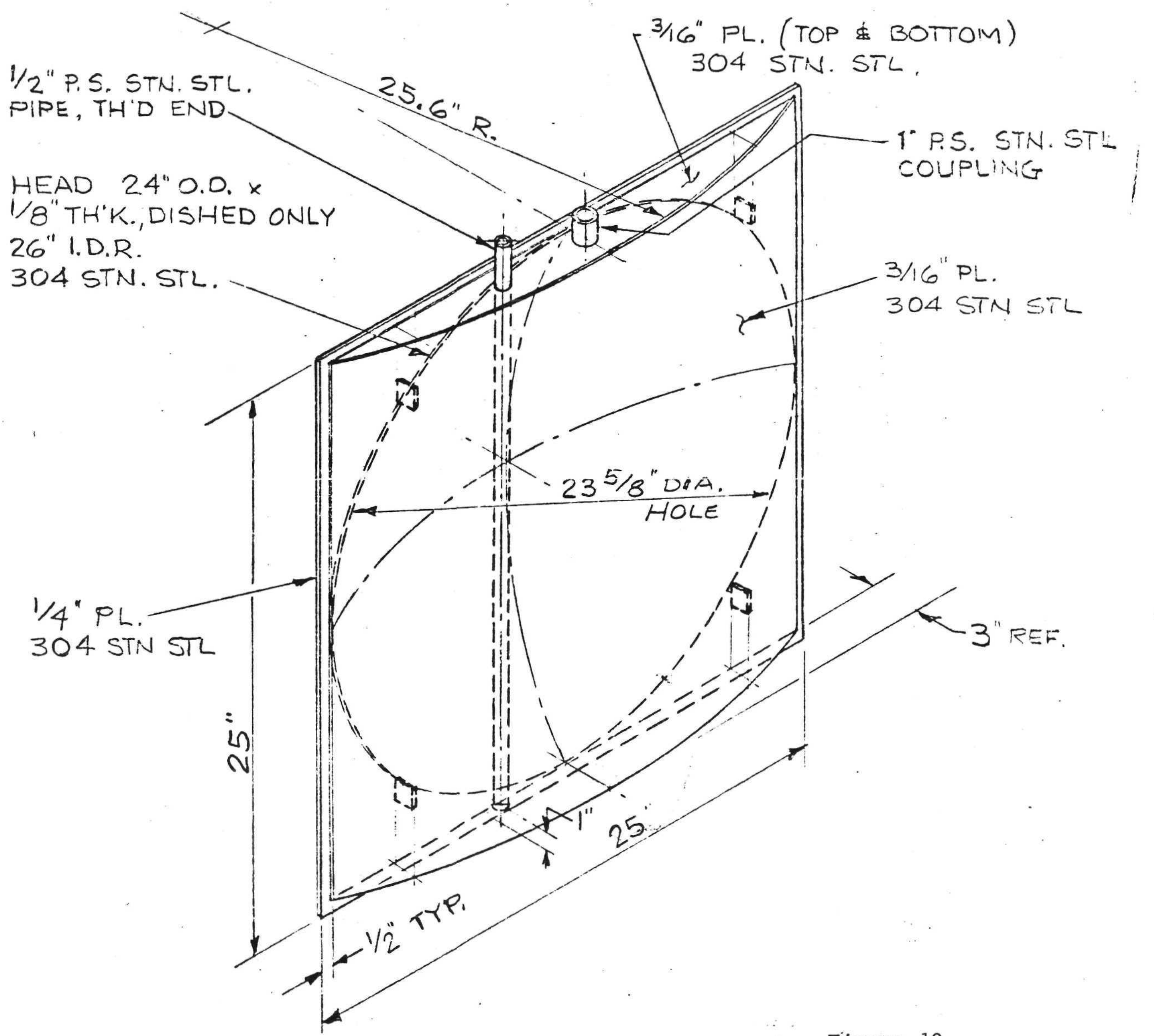


Figure 18

TITLE NASA-LEWIS CONTRACT #3-14366
TASK III TEST VESSEL

TOLERANCES UNLESS OTHERWISE NOTED: .X = ±.1, .XX = ±.06, ANGULAR ± °
MACHINED SURFACES SHALL BE √

SIMILAR TO

BY FSH DATE 10-14

SCALE

CHK'D

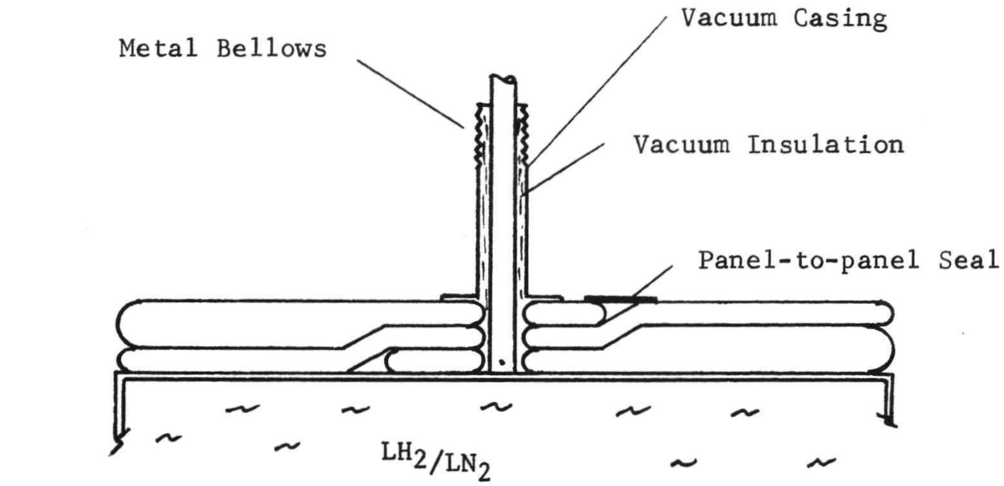
APPV'D

UNION CARBIDE CORPORATION
LINDE DIVISION
TONAWANDA, NEW YORK

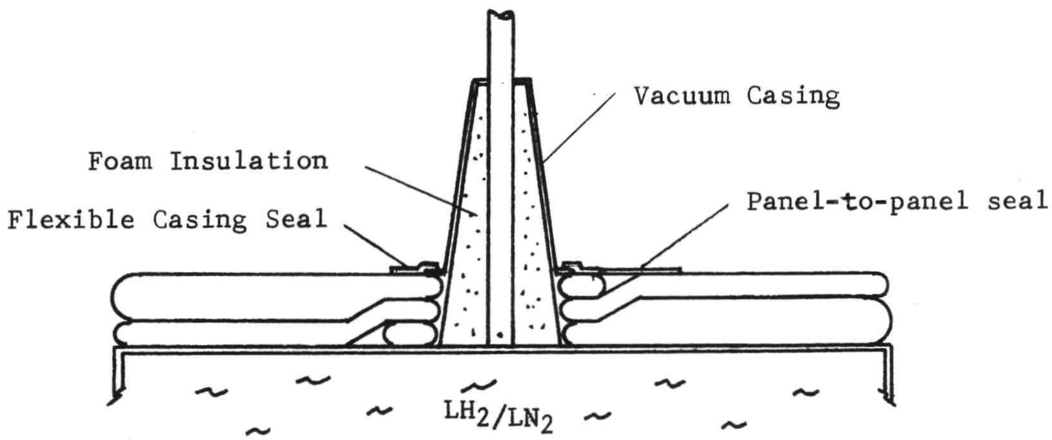
A-SK-108375

FIGURE 19

Penetration Seal Design Concepts



Semi-Rigid Penetration



Rigid Penetration

The purpose of the pressure cycling portion of the test was to evaluate the ability of the panels to withstand the cyclic nature of the external pressure on the panels. During a given flight, the external panel pressure will range from one atmosphere while on earth to vacuum when in space. For testing, the insulation system was installed in a vacuum chamber. The chamber pressure was then cycled between one atmosphere and vacuum to simulate atmospheric pressure changes during flight.

The purpose of the thermal exposure portion of the test was to evaluate panel performance in the proposed 300°F (149°C) environment of re-entry. Previous Task II screening tests provided continuous high temperature 300°F and 350°F (149°C and 177°C) data. Task IV testing provided data on cyclic temperature effects on the panels since the outer skin temperature was varied from 300°F (149°C) to 70°F (21°F) while the tank surface was continuously maintained at LN_2 temperature. The panels were evacuated and sealed off prior to and during the test. At the conclusion of testing (100 cycles), the panels were removed for leak checking, visual inspection, adhesive evaluation, and casing permeation tests.

4.3.1 Kapton/RTV System Test

4.3.1.1 Panel Fabrication

A total of four test panels (3 polar and 1 cylindrical, see Figure 3 of Section 6.3) and 3 dummy panels (1 polar and 2 cylindrical) were fabricated. Casing forming procedure was as follows: The 2 mil (0.05 mm) plain Kapton casing material was draped over the male aluminum stretching form and folded around the outer edges of the form. This material was then bonded to the underside of the form using 732 silicone adhesive. The adhesive functioned as a rough vacuum seal between the casing and the form. To insure no material slippage during evacuation, the edges of the casing were then clamped to the form. The whole stretching form assembly was then evacuated and placed in an oven at 750°F (399°C) for about 1 hour. It was then removed and quenched to ambient temperature by spraying with cold water. The draw in all cases was the full desired amount and was permanent. However, some problems were encountered when forming the polar panel casings. Several times the casings split during the vacuum forming process. This may have been as a result of handling prior to forming. Normal handling of the material does not effect the ambient temperature properties of the casing, but when combined with the stresses created in the forming process, could result in a casing rupture. This problem area would be magnified when larger scale panels are built and could cause serious forming difficulties.

Each test panel was composed of 6 shields and 7 spacers. The shields consisted of double aluminized Mylar for the inner two-thirds of each panel length, and double aluminized Kapton for the outer or exposed one-third. The spacers were also of a composite nature. The inner two-thirds of each panel length was made up of three layers of 0.024 in (0.61 mm)

thick, open-cell polyurethane foam. The bottom layer of the spacer was a plain sheet of foam while the other two layers were punched and staggered (see Figures 20 and 21). The outer one-third of each panel length used single layers of Dexiglas as the spacer material. The formed panel casings were bonded using Dow Corning 732 RTV silicone adhesive and cured overnight under 2 psi (13,790 N/m^2) pressure. The finished cylindrical test panel is shown in Figure 22. Note the keyhole shaped depression in the panel. This design will allow the penetration rod (see test plan, Section 6.3) to pass through the insulation panel while still maintaining the panel's vacuum integrity.

This keyhole shaped penetration area was a source of problems in each of the test panels. This area which has an inside radius of about 1 1/4 inches (3.18 cm) tended to tear very easily during handling prior to panel installation. Although the adhesive layer between the casing halves added some strength, any small nick in the Kapton casing material in this area could easily enlarge to span the entire joint width (recall the very low tear propagation resistance of Kapton, reference Table 2). This "notch sensitivity" or tear propagation problem is probably intensified by the residual stresses in the Kapton created during the heating/ fast cool forming process, and, coupled with the previously discussed forming problems suggest serious fabrication and handling problems may exist as the panels become larger.

Before installing the panels on the test vessel, each panel was leak checked to determine a base leak rate for the panel. For this test, the panel was connected to a Veeco MS-9 leak detector, and leak checked using a 0.1% helium in nitrogen gas mixture. Leak rate values for each test panel are shown in Table 10. To evaluate each panel for leak tightness, the panel leak rate and casing permeability were compared on a per square foot basis. Assuming that any panel leak rate above that of the casing material is due to permeation (or leakage) in the panel adhesive, each panel's leak tightness was established. Casing material permeability was determined using the procedure outlined in Contract No. NAS 3-12045 (see Section 6.4). The test apparatus for the casing tests is shown in Figure 23. All test panels were acceptable as indicated in Table 10 (test accuracy is judged about $\pm$ 15%). The slightly higher starting value for polar panel number 1 is probably due to a small leak or leaks somewhere in the adhesive joint.

4.3.1.2 Insulation System Installation

The test panels and dummy panels were attached to the test vessel using VELCRO fasteners. Masking tape was used to temporarily hold the outer edges of the panels from sliding during handling (see Figures 24 and 25, and also Figure 3 of Section 6.4). In order to keep the overall heat leak to the vessel at a minimum, a guard insulation system of open-cell polyurethane foam was cut to fit over the exposed tank surfaces, and then covered with 2 layers of Dexiglas to protect the foam from damage during the heating portion of the cycling tests. A layer of 2 mil (0.05 mm) plain

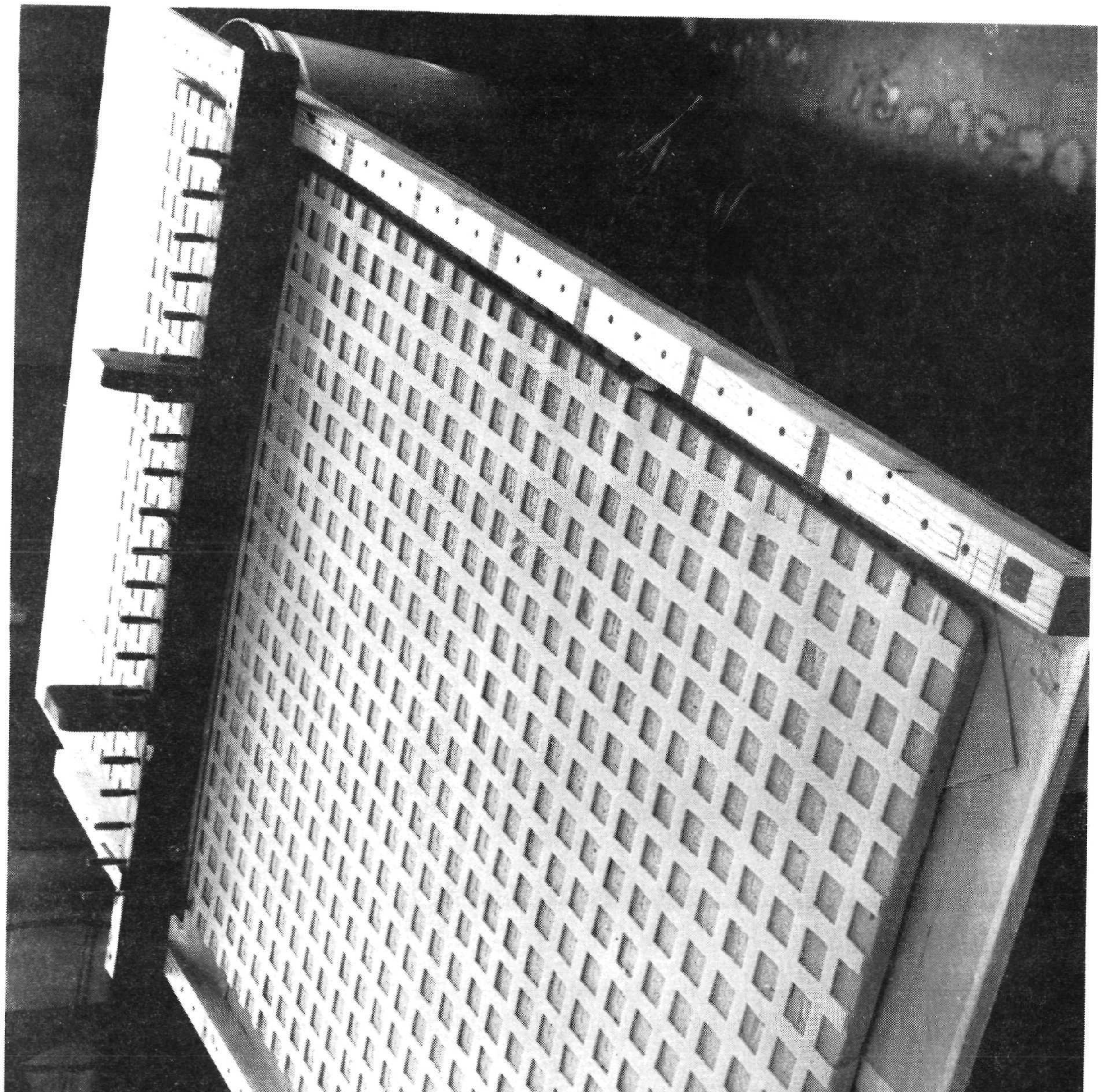


Figure 20

Foam Punching Operation

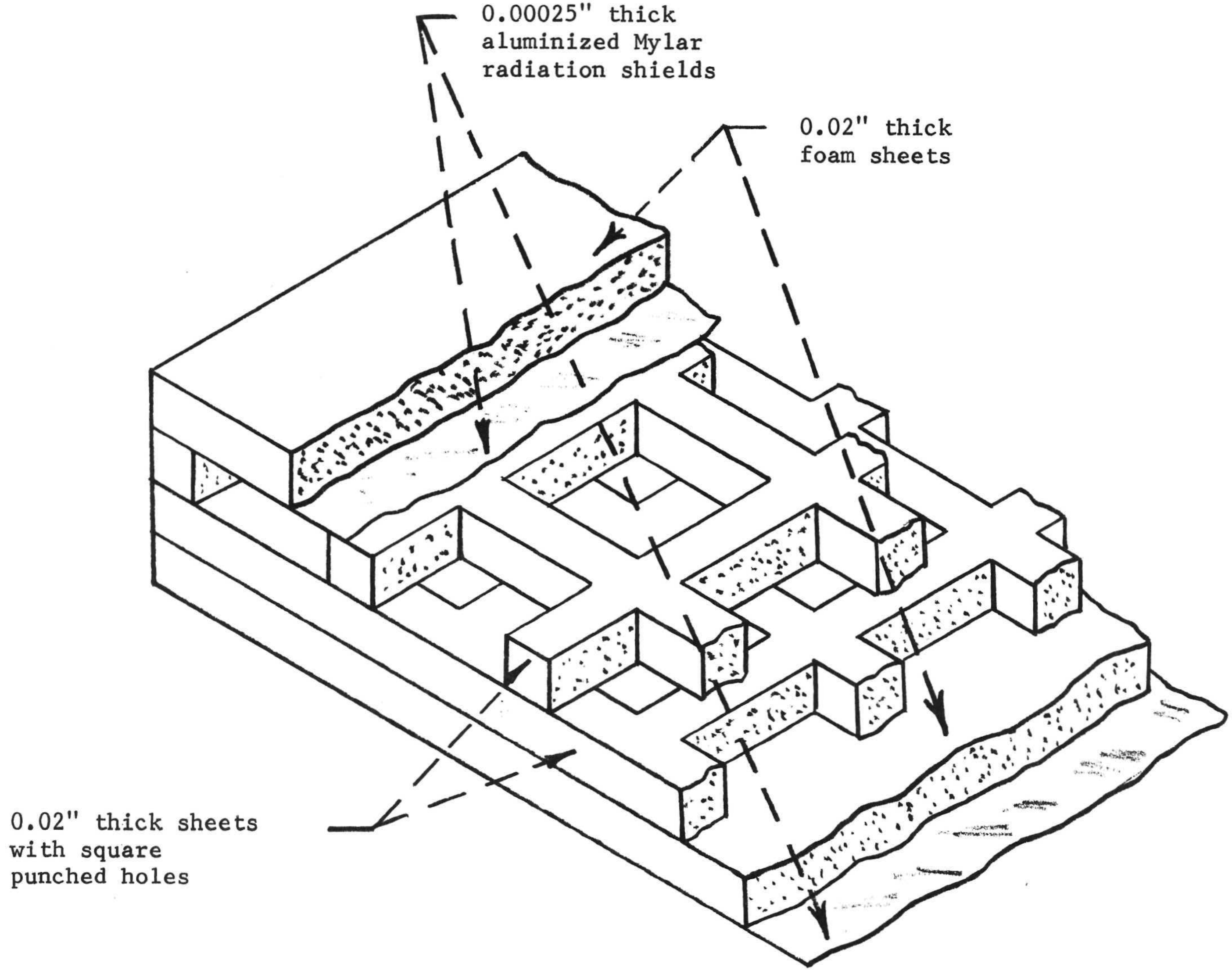


Figure 21

Punched Hole Spacer Configuration

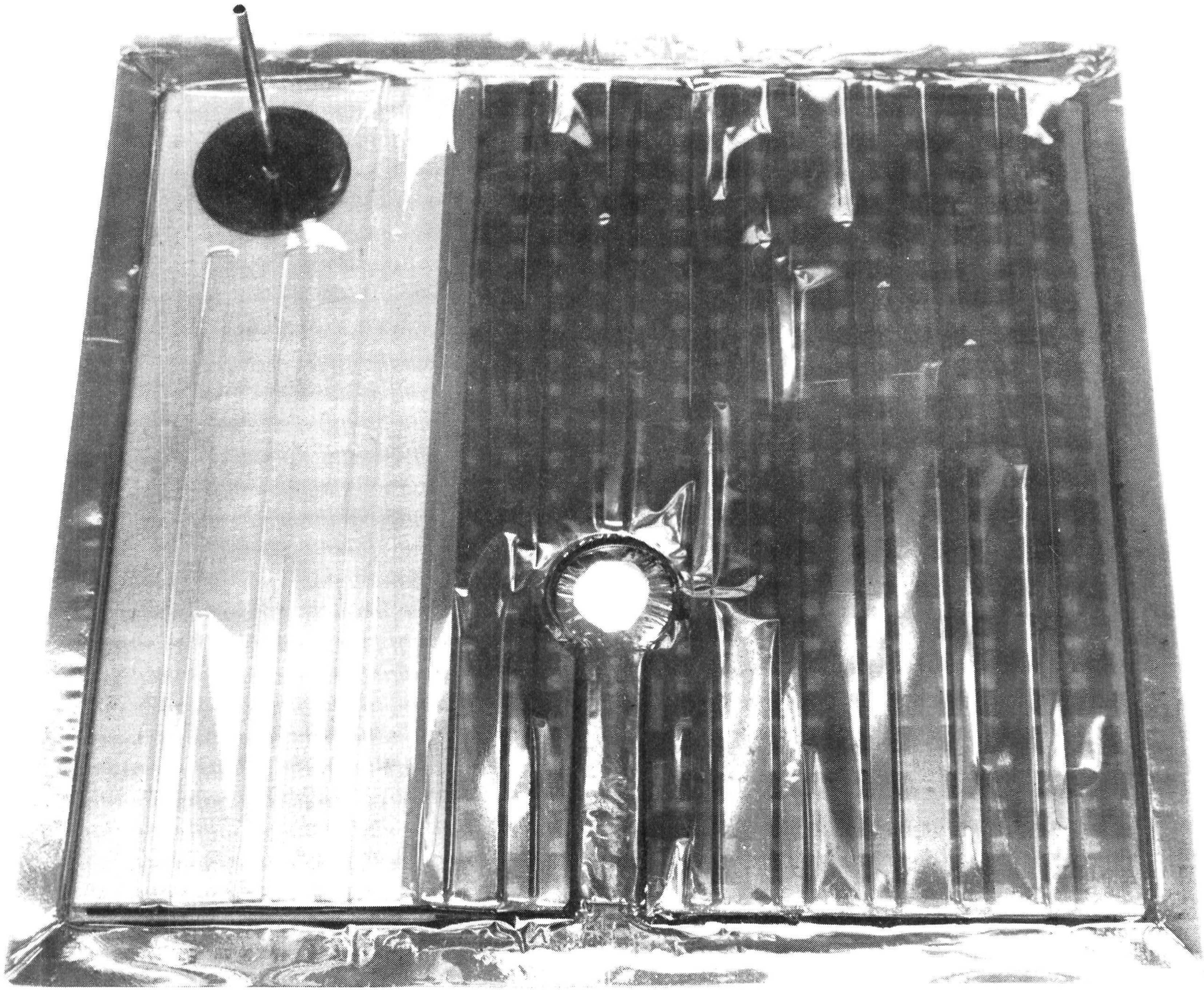


Figure 22

Completed Kapton/RTV Cylindrical Test Panel

TABLE 10

Task IV - Panel Pre-Test Helium Permeation Test Results

Panel	Panel Leak Rate atm-cc/sec.*	Panel Leak Rate Per Unit Area atm-cc/sec-ft^2
Cylindrical	20.38×10^{-3}	2.75×10^{-3}
Polar #1	10.71×10^{-3}	3.50×10^{-3}
Polar #2	7.47×10^{-3}	2.44×10^{-3}
Polar #3	7.19×10^{-3}	2.35×10^{-3}

NOTE: Base permeation for the 2 mil Type H casing material is 0.599×10^{-3} atm-cc/sec for a 6 1/4 inch diameter test section, and the permeation rate per unit area is 2.81×10^{-3} atm-cc/sec-ft^2.

* atm cc/sec He from a .1% He in N_2 mixture.

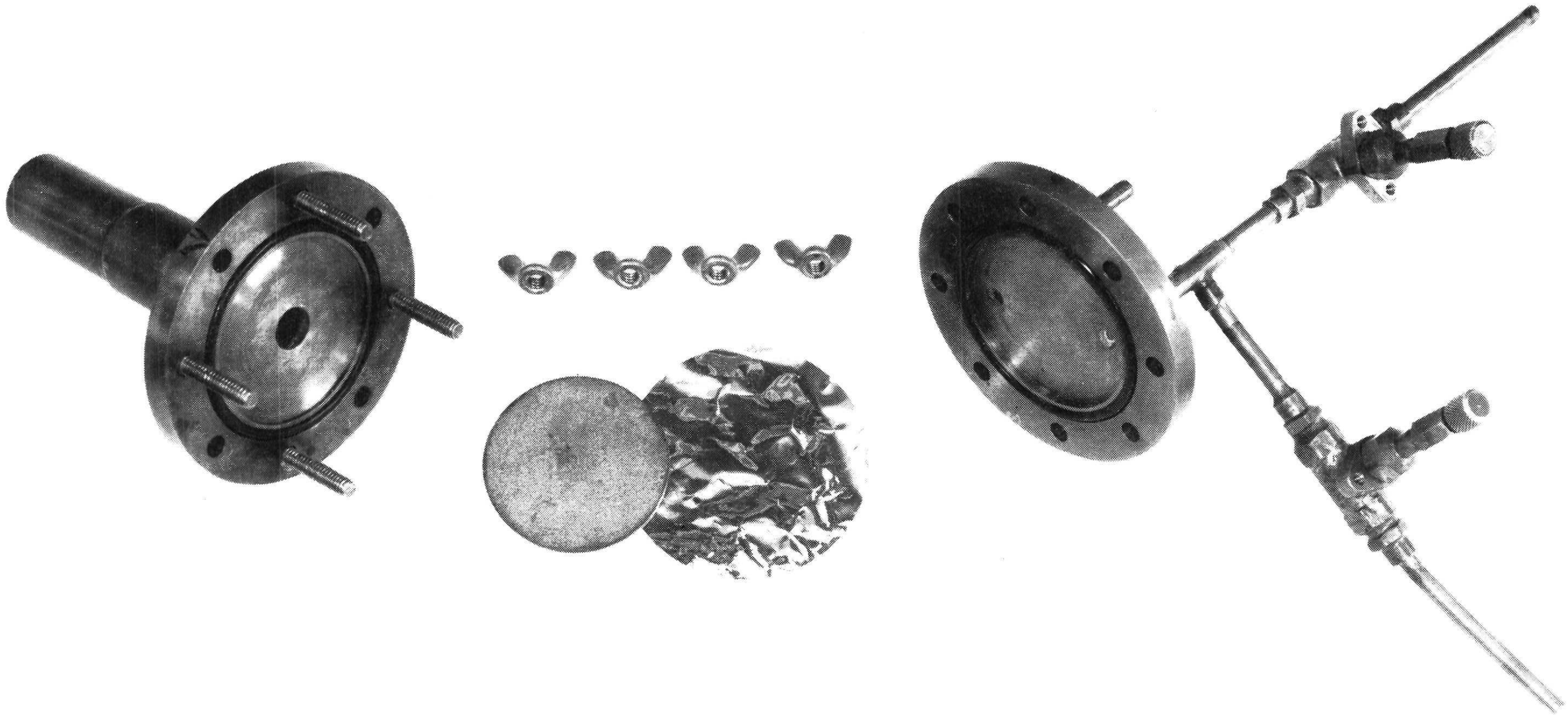


Figure 23

Casing Permeation Test Apparatus

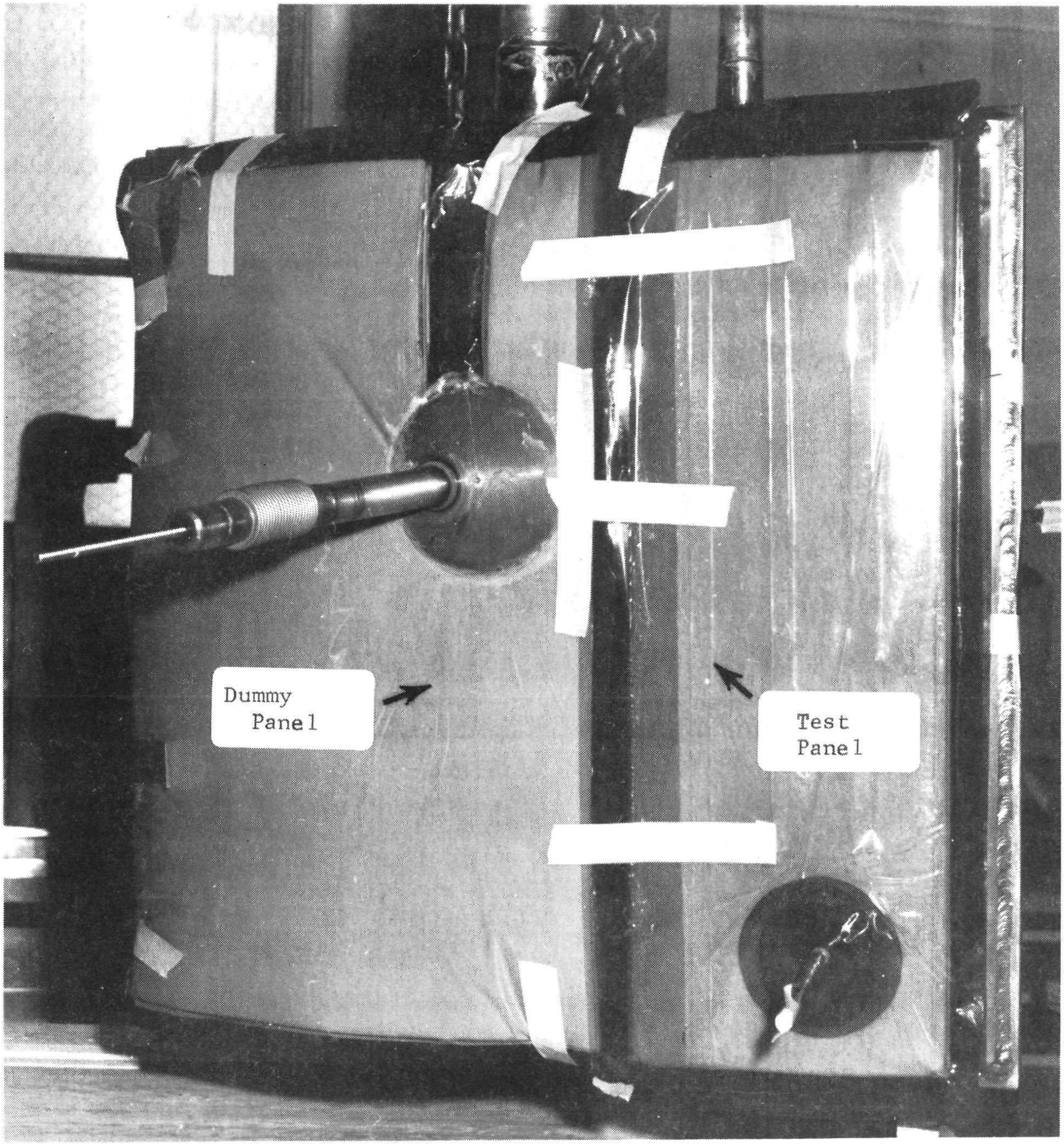


Figure 24

Kapton/RTV Cylindrical Panels in Place

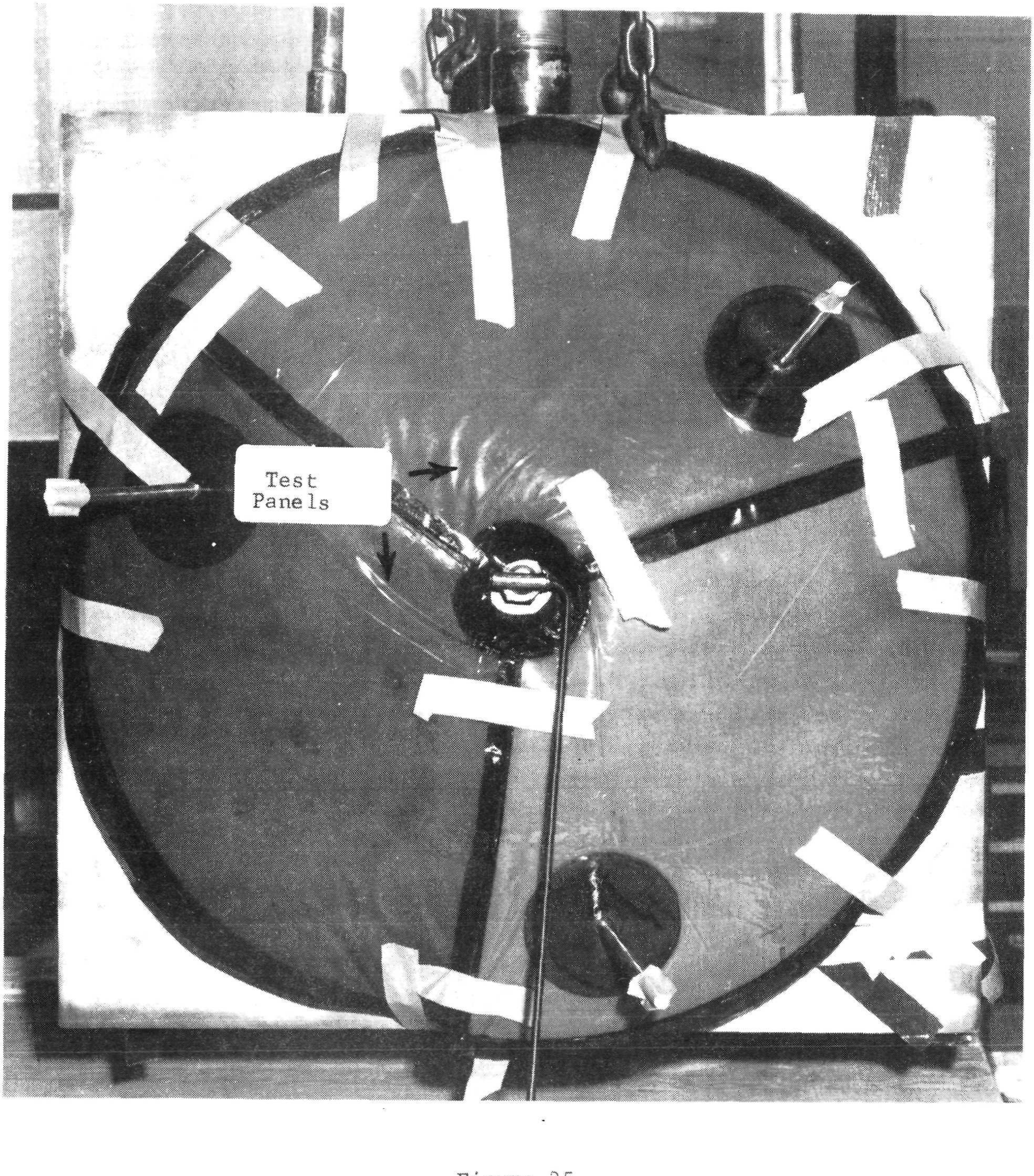


Figure 25

Kapton/RTV Polar Panels in Place

Kapton was placed over the glass and connected to the test panels to form a vacuum tight case around the test vessel (see Figures 26 and 27). This outer Kapton casing was bonded using the 732 RTV adhesive. An overall leak rate was determined for the entire system. The test procedure was the same as for the test panels. The system was determined to be leak tight when the total leak rate per square foot was approximately equal to that of the casing material i.e. about 3.2×10^{-3} atm-cc $_2$/sec-ft (2.97×10^{-4} atm-cc/sec-m^2). Figures 26 and 27 show the test panels, guard insulation and outer casing in place prior to leak test.

4.3.1.3 Test Procedure and Results

Figure 28 shows the test vessel positioned in the test chamber. The metal screen covering the guard insulation holds the electric heating tapes in place and protects the insulation from damage during handling. The semi-rigid type penetration rod installed on the cylindrical side of the test vessel was attached by a connecting rod to a metal bellows which deflected when the test chamber was evacuated, delivering the desired motion to the penetration rod. Figure 28 also shows each test panel, as well as the space behind them, connected through a manifold system to a vacuum pump. LN_2 fill and venting is through the top of the test chamber.

The test cycle sequence is shown in Figure 29. The total time per cycle is approximately 3 hours. During the entire test cycle, the liquid level in the test vessel was maintained by a level controller which operated a solenoid valve between the test vessel and an LN_2 dewar. Thermocouples placed on the panel surface as well as on the heaters monitored panel and heater temperatures during all phases of the test (see Task IV test plan, Section 6.3).

At the conclusion of the 13th cycle, the test vessel was removed from the chamber and each panel leak checked in place. To accomplish this, the space behind the panels was evacuated and backfilled with a 0.1% He in N_2 gas mixture. The entire test vessel was placed in a polyethylene bag which also contained the test gas. Since each test panel was completely surrounded by the test gas, it could be helium leak checked in place. Results from the leak checks (see Table 11) indicated that two of the polar panels had developed large leaks. Since the panels could be evacuated when the space behind them was being evacuated, it was concluded that the leaks had developed on the inside, unexposed portion of each panel. The cylindrical panel showed an increase in leak rate by a factor of 2, indicating a small leak had developed.

The test vessel was then reinstalled in the chamber. The panels were not repaired prior to continuing the test because they could still be evacuated from behind during the test through the guard insulation vacuum port.

After the 100 test cycles had been completed, the test vessel was removed from the vacuum chamber for further examination. Panel-to-panel

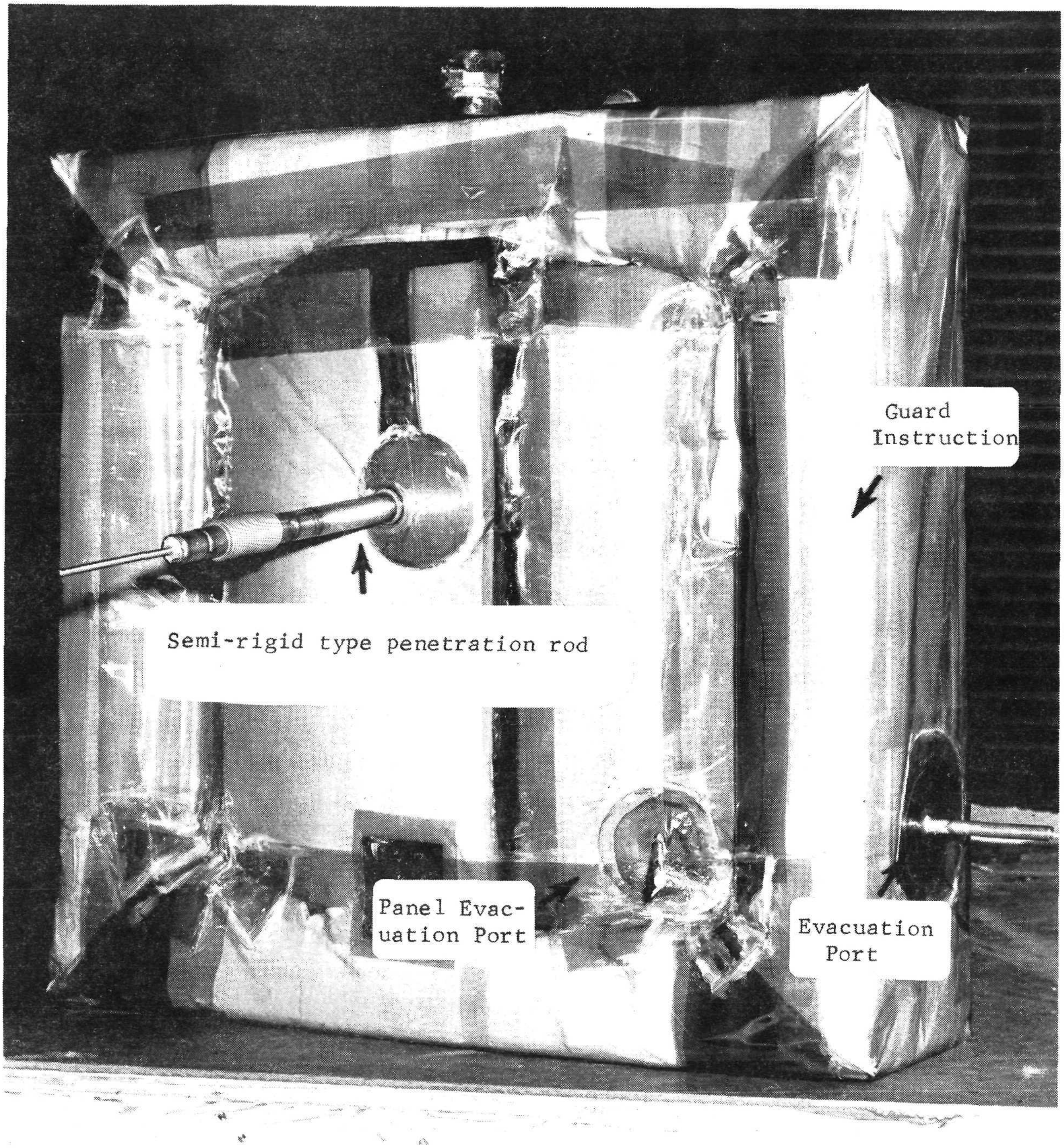


Figure 26

Outer Casing Installed - Cylindrical Test Surface

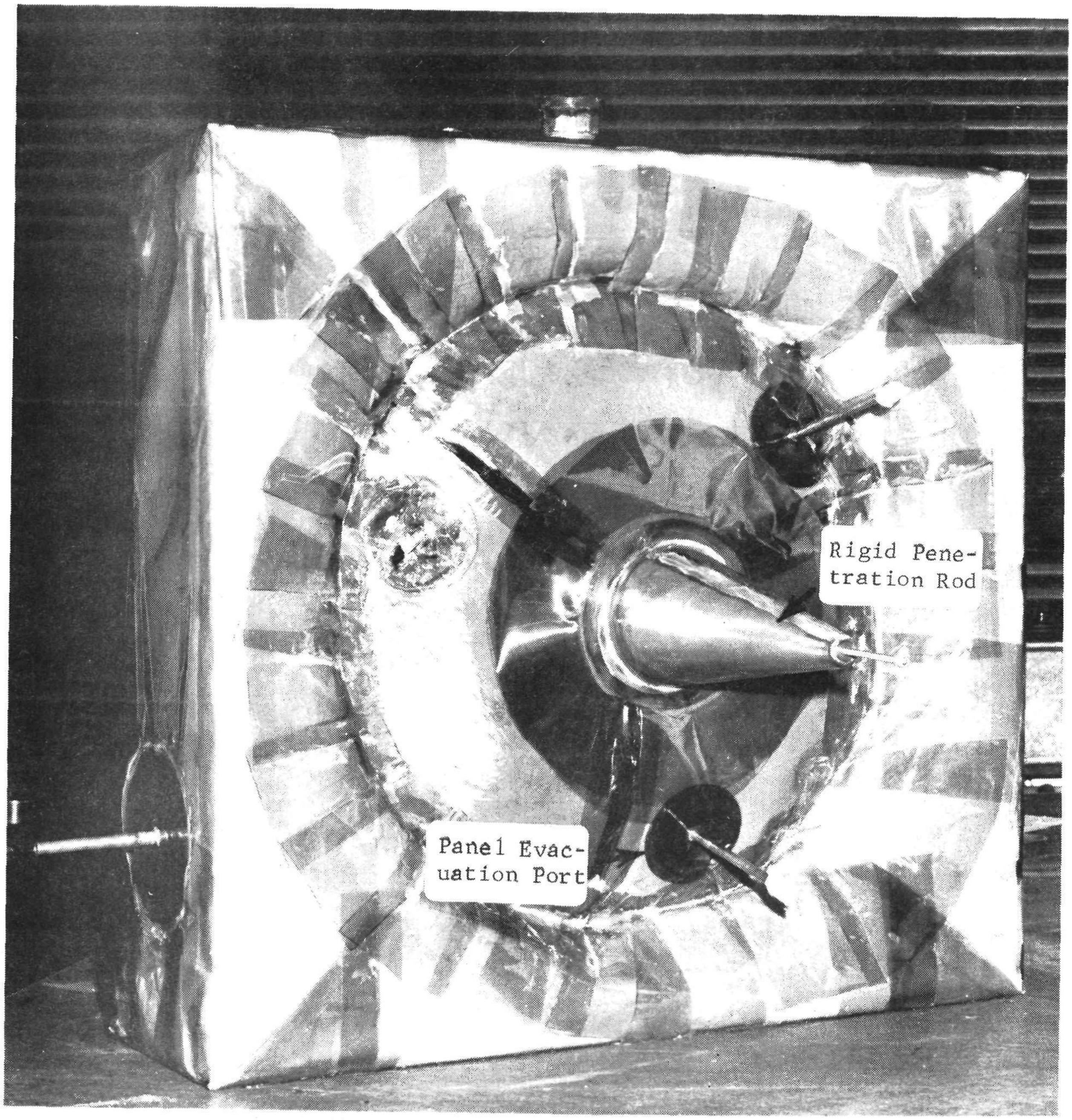


Figure 27

Outer Casing Installed - Shperical Test Surface

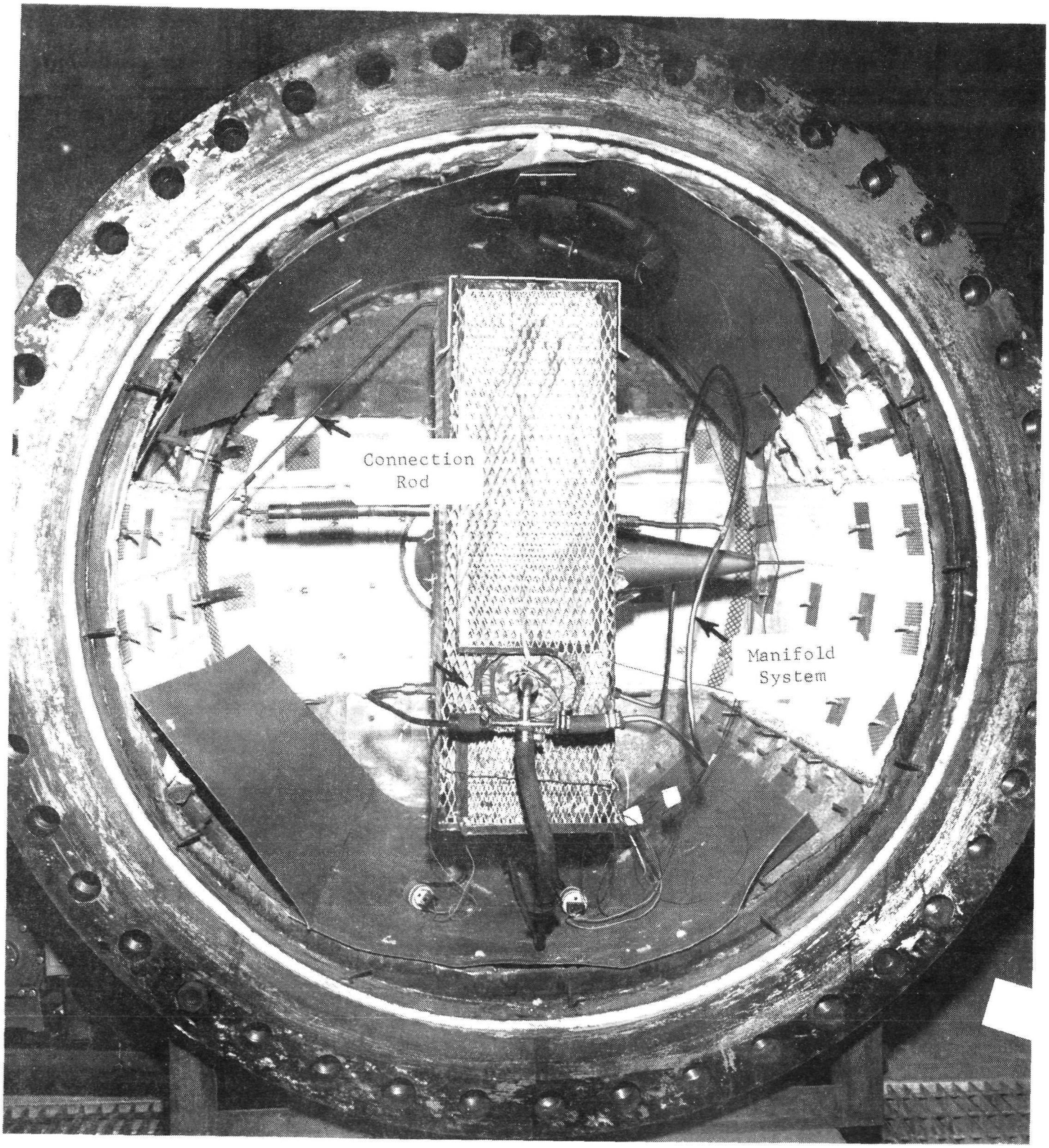


Figure 28

TASK IV Test Apparatus

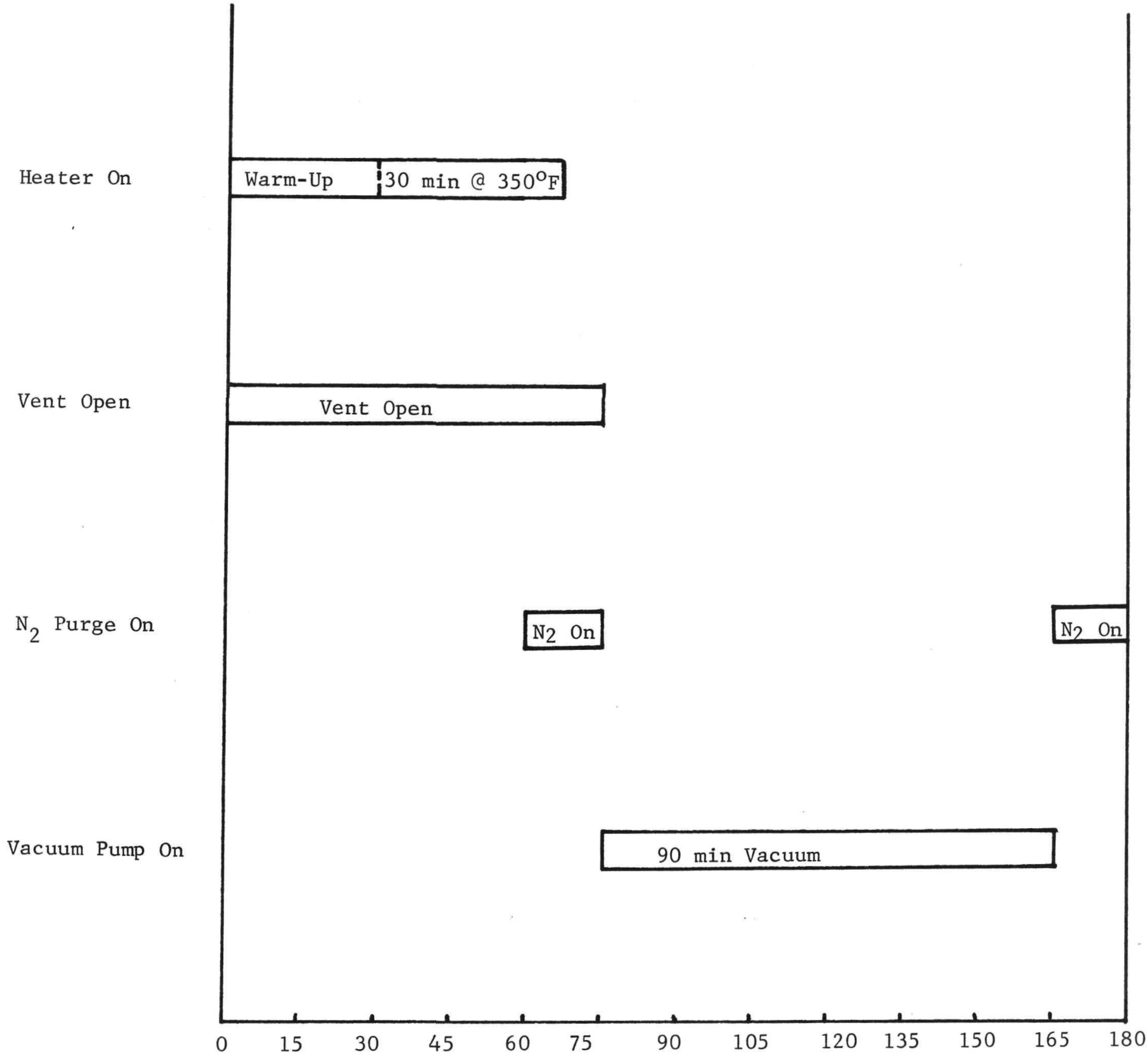


Figure 29 Time Sequence of Task IV Test

TABLE 11

TASK IV - Panel Helium Permeation Test Results

Panel	No. Cycles	Panel Leak Rate * atm-cc/sec.	Panel Leak Rate per unit area atm-cc/sec-ft^2
Cylindrical	0	20.38×10^{-3}	2.75×10^{-3}
	13	51.50×10^{-3}	6.95×10^{-3} (Small
	100	53.13×10^{-3}	7.17×10^{-3} Leak)
Polar No. 1	0	10.71×10^{-3}	3.50×10^{-3}
	13	Leak	Leak
	100	Leak	Leak
Polar No. 2	0	7.47×10^{-3}	2.44×10^{-3}
	13	Leak	Leak
	100	Leak	Leak
Polar No. 3	0	7.19×10^{-3}	2.35×10^{-3}
	13	7.99×10^{-3}	2.61×10^{-3}
	100	8.93×10^{-3}	2.92×10^{-3}
System	0	54.72×10^{-3}	3.2×10^{-3}
	13	61.56×10^{-3}	3.6×10^{-3}
	100	70.11×10^{-3}	4.1×10^{-3}

NOTE: Base permeation for the as received 2 mil type H Kapton casing material is 0.599×10^{-3} atm-cc/sec. for a 6¼ inch diameter test section, and the permeation rate per unit area is 2.81×10^{-3} atm-cc/sec-ft^2.

* atm-cc/sec of He from a .1% He in N_2 gas mixture.

seals remained functional. Figure 30 shows the heating units and test vessel prior to removing the insulation panels. After a visual inspection of the insulated test vessel, the guard insulation and the individual panels were removed to facilitate further panel investigation (see Figure 31). Examination of the penetration area on the two faulty polar panels revealed that leakage had developed in areas which had been repaired prior to panel installation. Tears in the adhesive joint area resulting from panel handling had required application of these patches in the penetration area of each panel. The patches on the cylindrical panel and third polar panel remained intact. These patches were bonded to both the panel casing and the actual panel adhesive joint, while the two patches which failed were bonded only to the adhesive joint area. This indicates that the patching technique employed to repair the torn Kapton was inadequate.

A leak check of the two good panels (cylindrical and polar #3) showed very little change from the 13 cycle leak rate. The test results are summarized in Table 11. A check of the casing material permeation revealed that the operating temperature had little effect on the permeation characteristics of the Kapton. Table 12 shows that samples cut from areas exposed to high temperature, intermediate temperature, and low temperature all exhibited about the same helium permeation rates after 100 test cycles. The low values could be in part due to the estimated $\pm$ 15% accuracy of the test (i.e. instrument accuracy, film property variations, variations in test gas mixture, etc.)

The RTV adhesive joints with the exception of the patches on the polar panels functioned well. Panel-to-panel seals were easily installed and withstood the required flexing and temperature exposure. Panel adhesive joints although somewhat thicker than the optimum 5-7 mil (.127 - .178 mm) on some cold joints, functioned adequately. Peel samples taken from hot, intermediate and cold temperature joints indicated peel strengths of 9-12 lbf/in (1609 - 2145 gms/cm). Sample joints tested for peel strength prior to panel cycling showed similar strengths.

Overall panel dimensions remained about the same with the exception of thickness. The three layered foam spacer retained about 75% of its thickness after the cyclic testing while the glass spacer retained about 85% of its thickness.

4.3.2 Polyester/RTV System Test

Casings were vacuum formed from 3 mil (0.076 mm) type 300 S Mylar polyester film using a heat gun and wooden female mold. Penetration areas were vacuum formed at 400°F (204°C) in an oven using an aluminum form. These areas were then bonded to the main casing to form a leak tight vacuum barrier. Figure 32 shows one-half of a penetration area after vacuum forming. Each test panel was filled with 6 shields and 7 spacers. The shields consisted of aluminized Mylar for the inner (cold) two-thirds of each panel length and aluminized Kapton for the outer or exposed one-

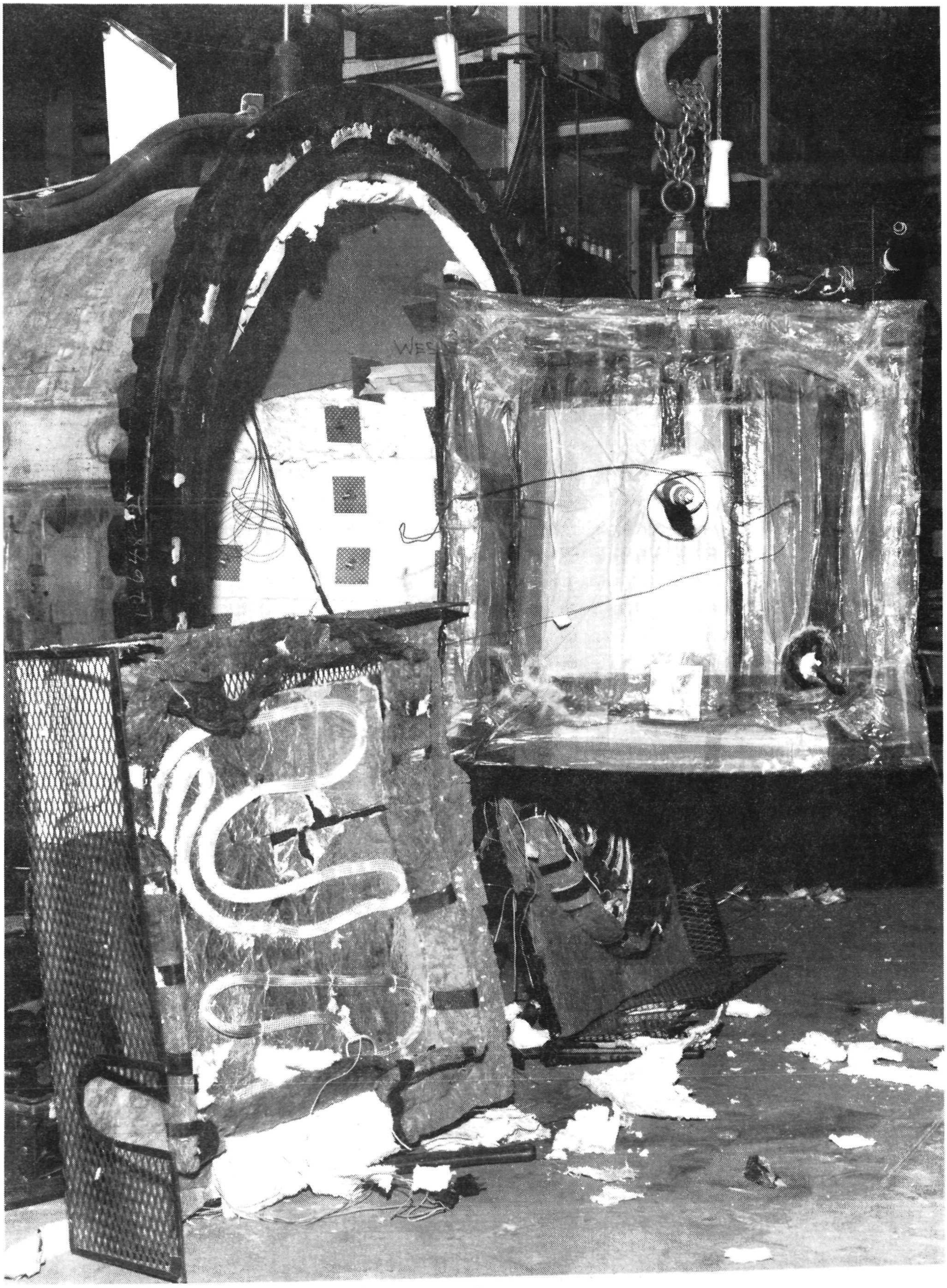


Figure 30

TASK IV - Vessel and Heating Units

Kapton/RTV Polar Panels After Completion of Testing

Figure 31

TABLE 12

TASK IV - Panel Casing Helium Permeation Test Results

Sample Location	Casing Permeation per unit area atm-cc/sec-ft^2 *
High Temperature	2.19×10^{-3}
Intermediate Temperature	2.11×10^{-3}
Low Temperature	2.07×10^{-3}
As Received	2.81×10^{-3}

NOTE: Base permeation for the as received 2 mil Type H Kapton casing material is 2.81×10^{-3} atm-cc/sec-ft^2 for a 6¼ inch diameter test section.

* atm-cc/sec-ft^2 of He from a 0.1% He in N_2 gas mixture.

Figure 32 - Formed Penetration Area Casing

third. The spacers were also of a composite nature. The inner two-thirds of each panel length was made up of three layers of 0.024 inch (0.61 mm) thick, open cell polyurethane foam, punched and staggered as on previous panels. The outer one-third of each panel length used single layers of Dexiglas as the spacer material. Figures 33 and 34 show a completed polar and cylindrical panel. Adhesive joint thickness ranged from about 10 mils (.25 mm) on the polar panels to 15-20 mils (.38 - .51 mm) on the cylindrical panel. A 5-8 mil (.13 - .20 mm) adhesive joint thickness was found to be most desirable in the cold flex tests summarized in Table 5. All cylindrical and polar panels were assembled using the same technique, yet one panel had a much thicker joint. This points out the fact that a better means of controlling the joint thickness must be developed to insure more uniform panels.

The completed panels were leak checked and attached to the vessel using "VELCRO" fasteners as on the previous test. Figures 35 and 36 show the panels installed on the test vessel. An aluminum jacket was placed around the foam guard insulation (replacing the Kapton sheet used on the previous test) to prevent damage during handling. Seals made from the aluminum jacket to the panels were made with Kapton while, panel-to-panel seals were made with polyester film. The dummy panels from the previous test (Kapton/RTV) were reused.

Guard insulation material was changed from low density open-cell urethane to Gypsum's Zer-O-Cell Blue foam to improve its temperature resistance.

Figure 37 shows the test vessel positioned in the test chamber prior to the start of testing. A thin copper foil was placed between the heating tapes and insulation surface for this test in an attempt to better distribute the heat to the insulation panels. The semi-rigid type penetration rods were installed on both sides of the test vessel and were flexed with each cycle as on the previous test. Each test panel as well as the space behind the panels was connected through a manifold system to a vacuum pump. The pump ran continuously throughout the test to simulate cryopumped panels. LN_2 fill and vent was through the top of the large chamber. The test cycle proceeded as on the previous Kapton/RTV test (see also Task IV test plan, Section 6.3) except that the upper limit of +300°F (149°C) was used instead of the +350°F (177°C) limit.

At the conclusion of the 100th cycle, the test vessel was removed from the test chamber for further evaluation (see Figure 38). Panel-to-panel seals remained functional as evidenced by the leak check data (see Table 13). After a visual inspection of the insulated test vessel, the guard insulation and the individual panels were removed to facilitate further panel investigation (see Figures 39 and 40). A helium leak check of the three polar panels showed they had changed little from their pre-test readings (Table 13). Examination of the cylindrical panel however, revealed that the cold joint area had failed. Many small cracks had developed in the adhesive joint (see Figure 41). Joint thickness was beyond the recommended .5-8 mils (.13 - .20 mm).

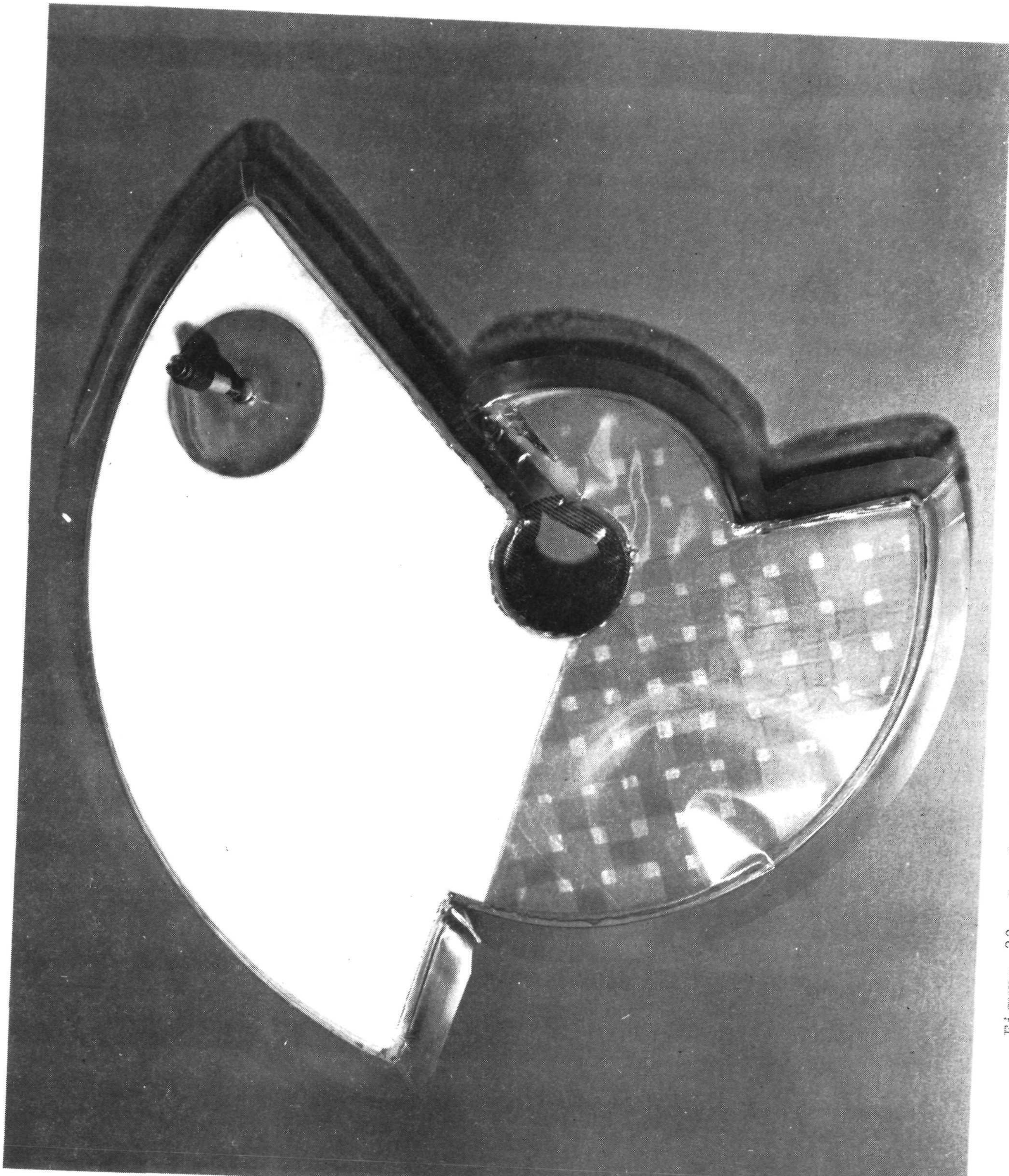


Figure 33 - Completed Polyester/RTV Polar Panel

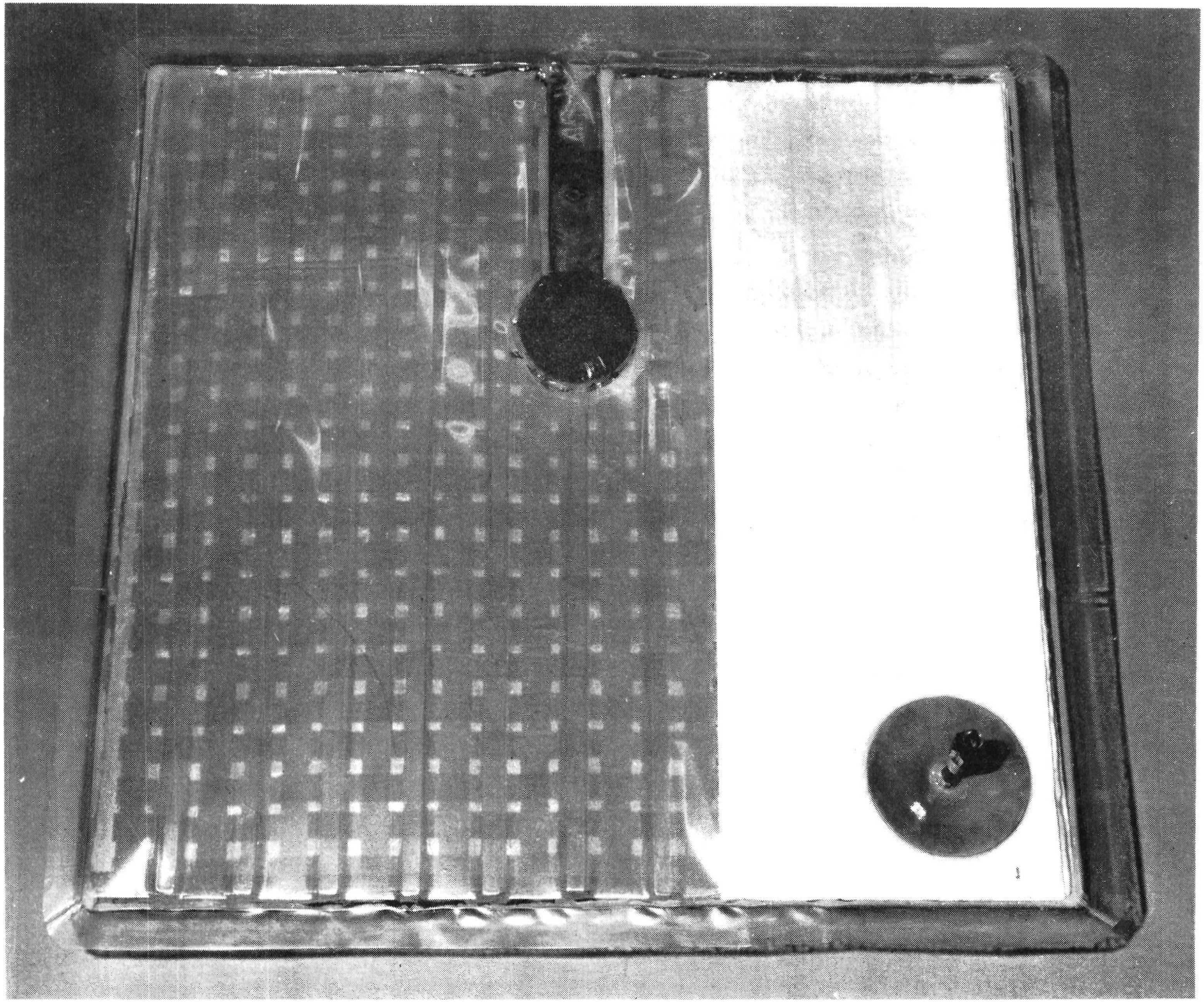


Figure 34 - Completed Polyester/RTV Cylindrical Panel

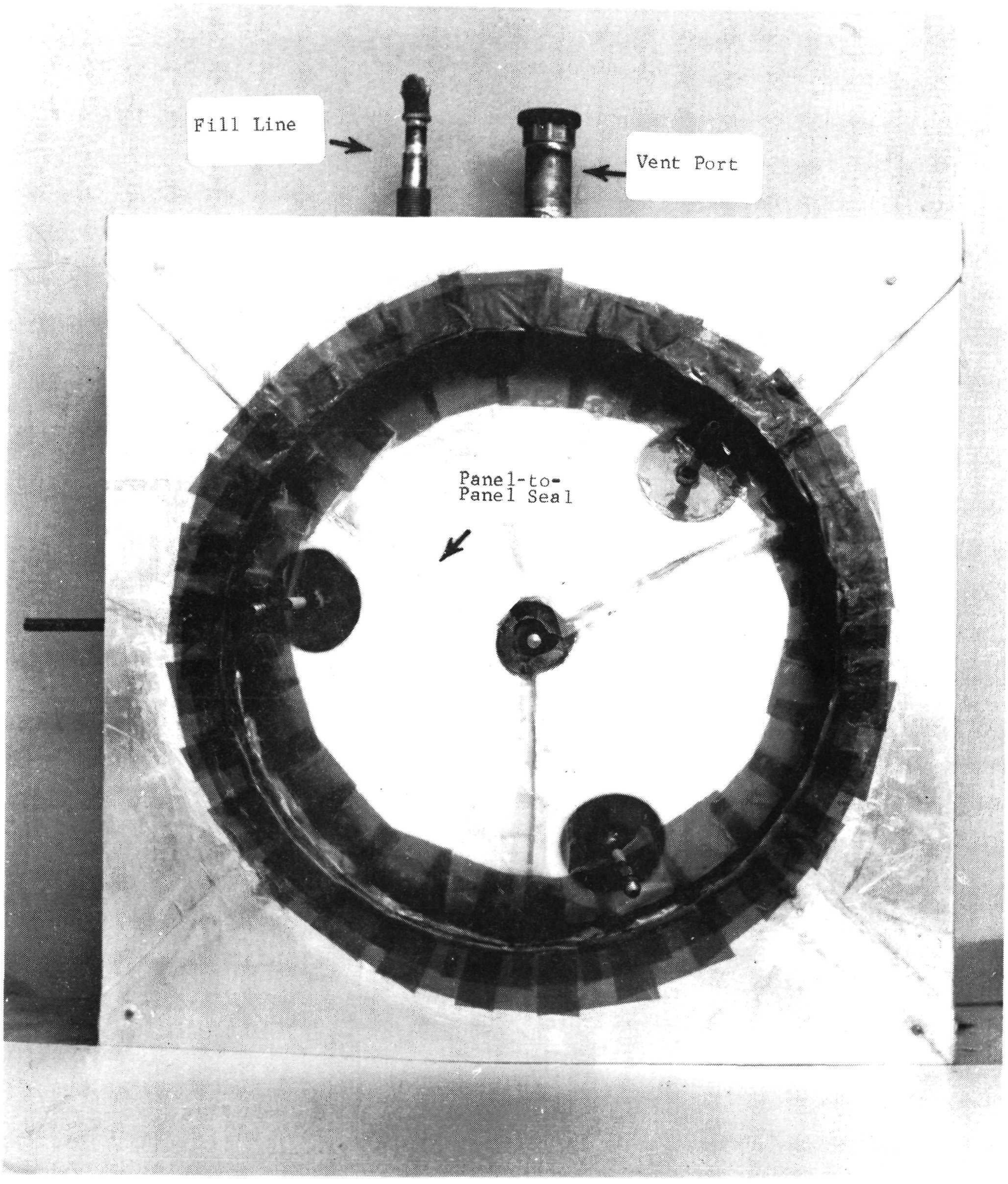


Figure 35 - Task IV Test Apparatus - Polar Side

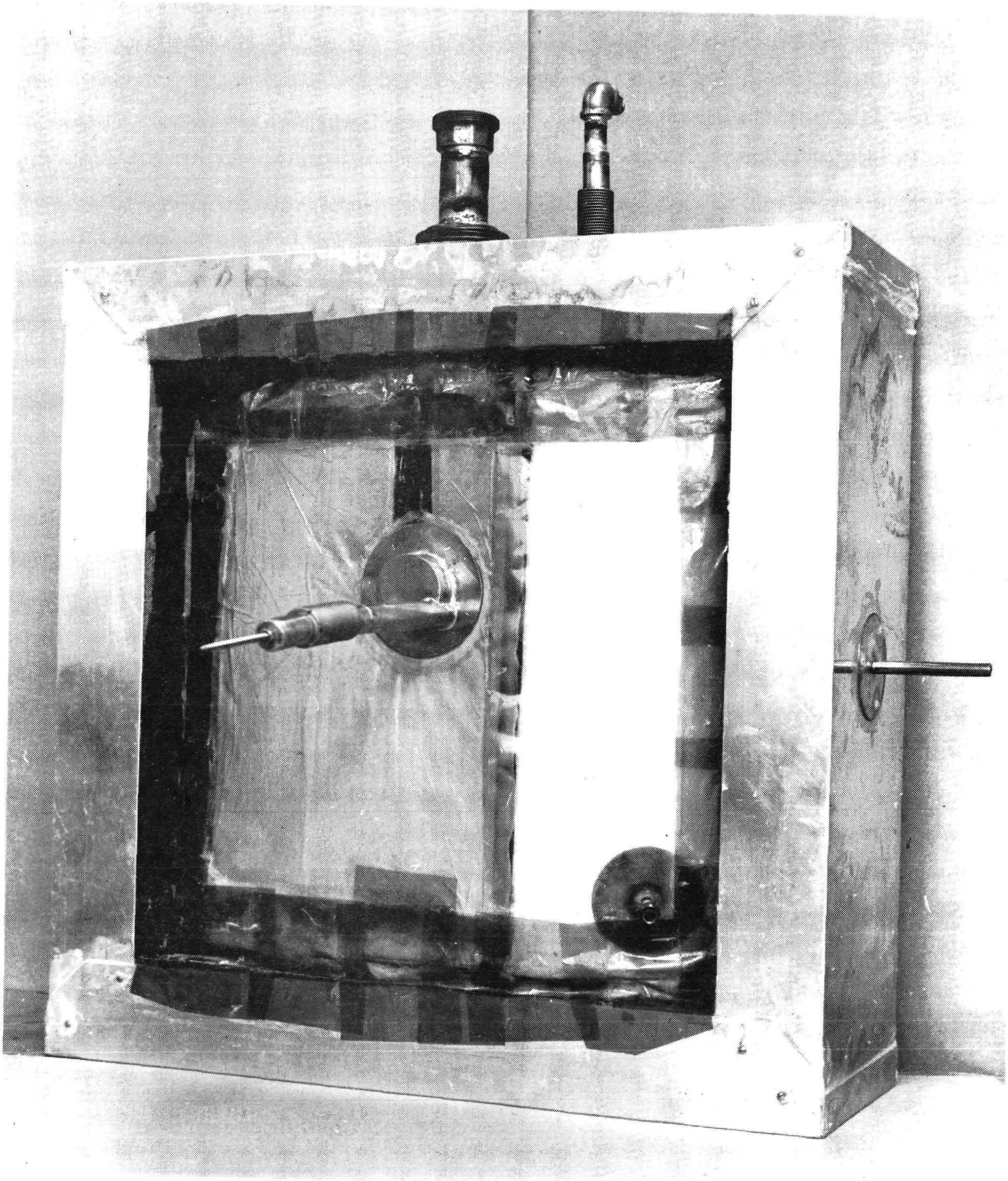


Figure 36 - Task IV Test Apparatus - Cylindrical Side

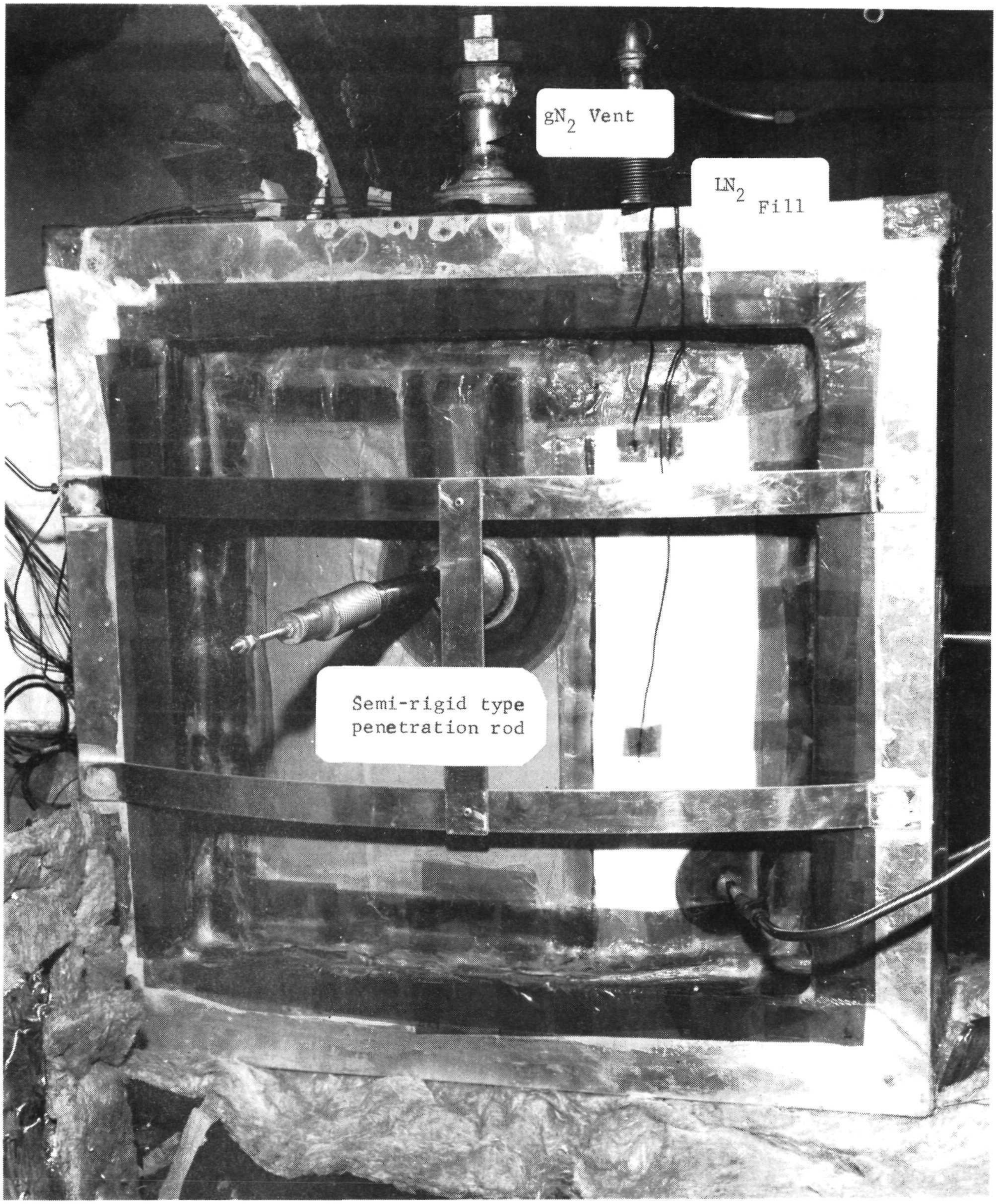


Figure 37

Cylindrical Side of Test Vessel Prior to Testing

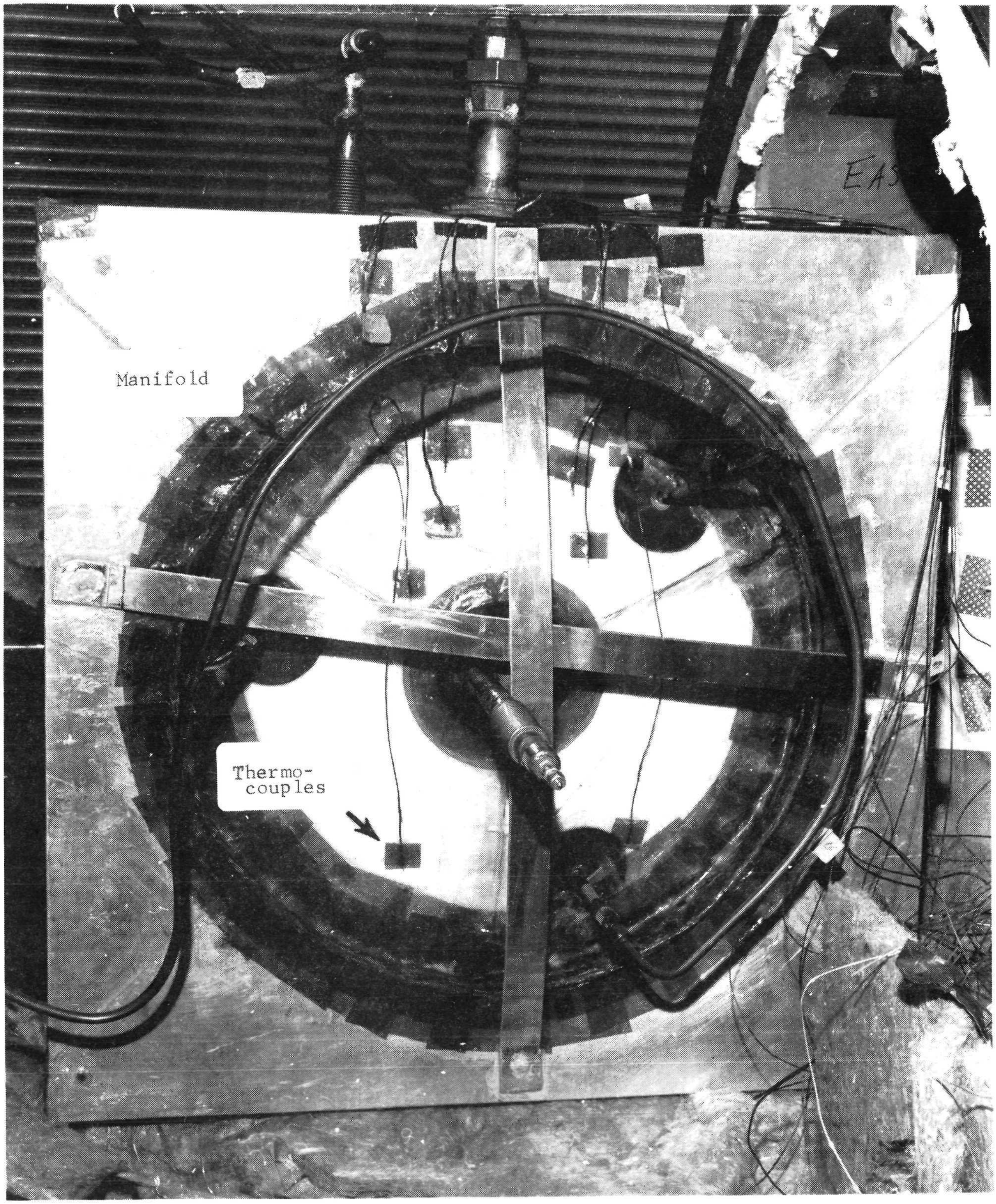


Figure 38

Polar Side of Test Vessel After Testing

TABLE 13

POLYESTER/RTV TASK IV PERMEATION TEST RESULTS

Panel	No. Cycles	Panel Leak Rate * atm cc/sec.	Panel Leak Rate/Unit Area atm cc/sec - ft^2
Cylindrical	0	6.01×10^{-3}	8.11×10^{-4}
	100	Leak	Leak
Polar #1	0	2.46×10^{-3}	8.04×10^{-4}
	100	2.66×10^{-3}	8.68×10^{-4}
Polar #2	0	2.54×10^{-3}	8.31×10^{-4}
	100	2.67×10^{-3}	8.72×10^{-4}
Polar #3	0	2.52×10^{-3}	8.24×10^{-4}
	100	2.51×10^{-3}	8.19×10^{-4}

* atm-cc/sec of He from a 0.1% He in N_2 gas mixture

NOTE: Base permeation for the as received 3 mil type 300 S Mylar polyester material is 1.67×10^{-4} atm-cc/sec. for a 6-1/4 inch diameter test section, and the permeation rate per unit area is 7.84×10^{-4} atm-cc/sec-ft^2.

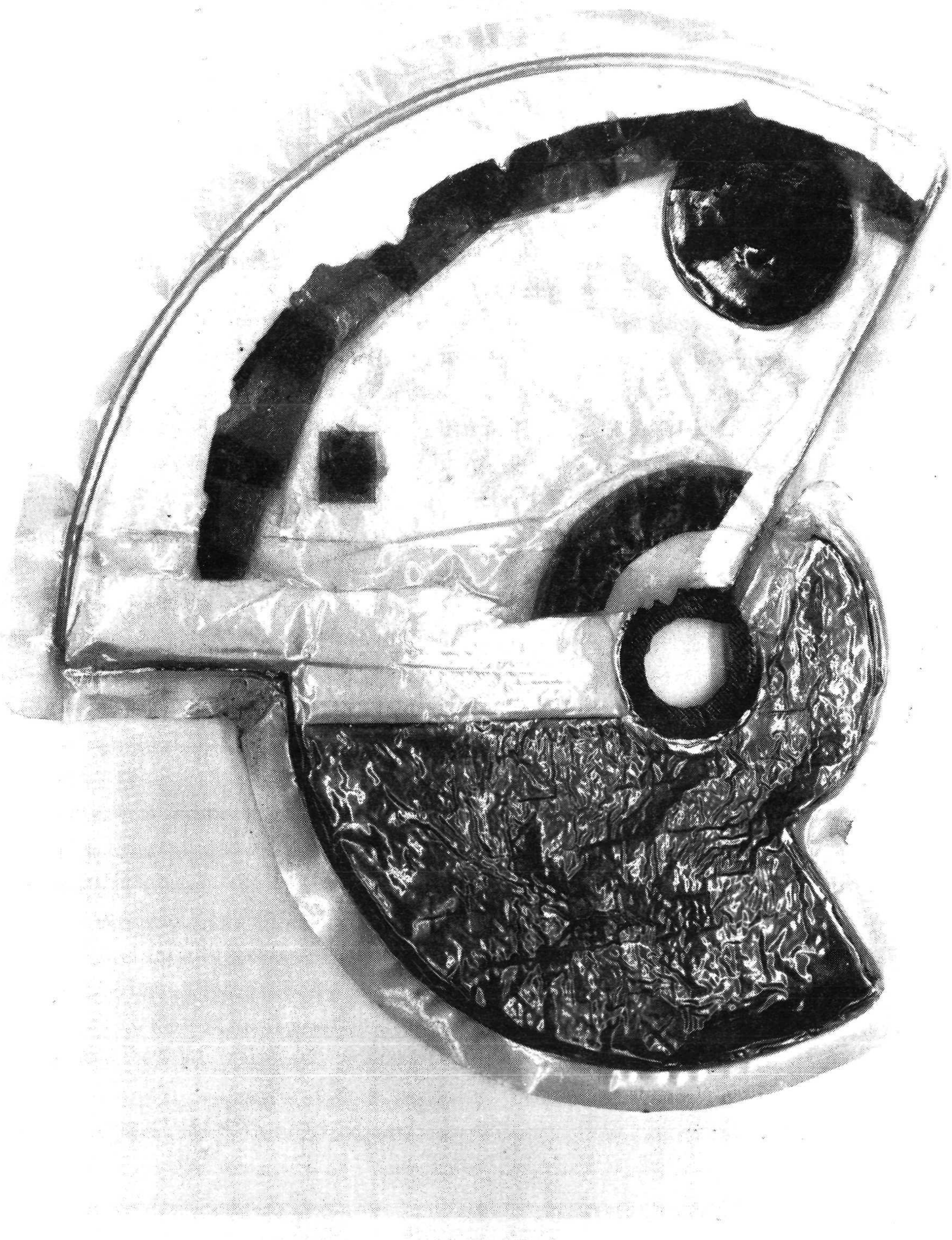


Figure 39 - Polyester/RTV Polar Panel After Testing

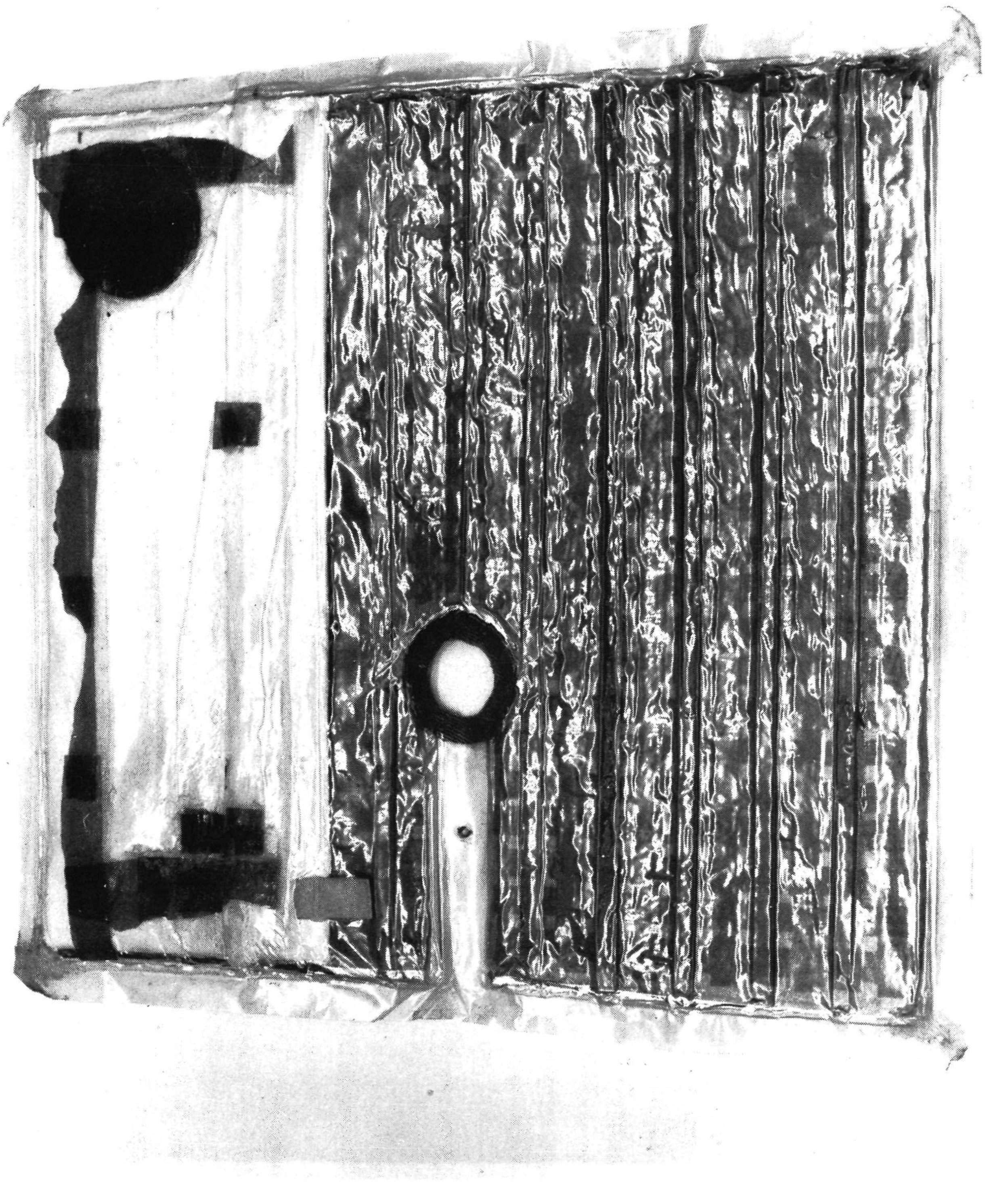


Figure 40 - Polyester/RTV Cylindrical Panel After Testing

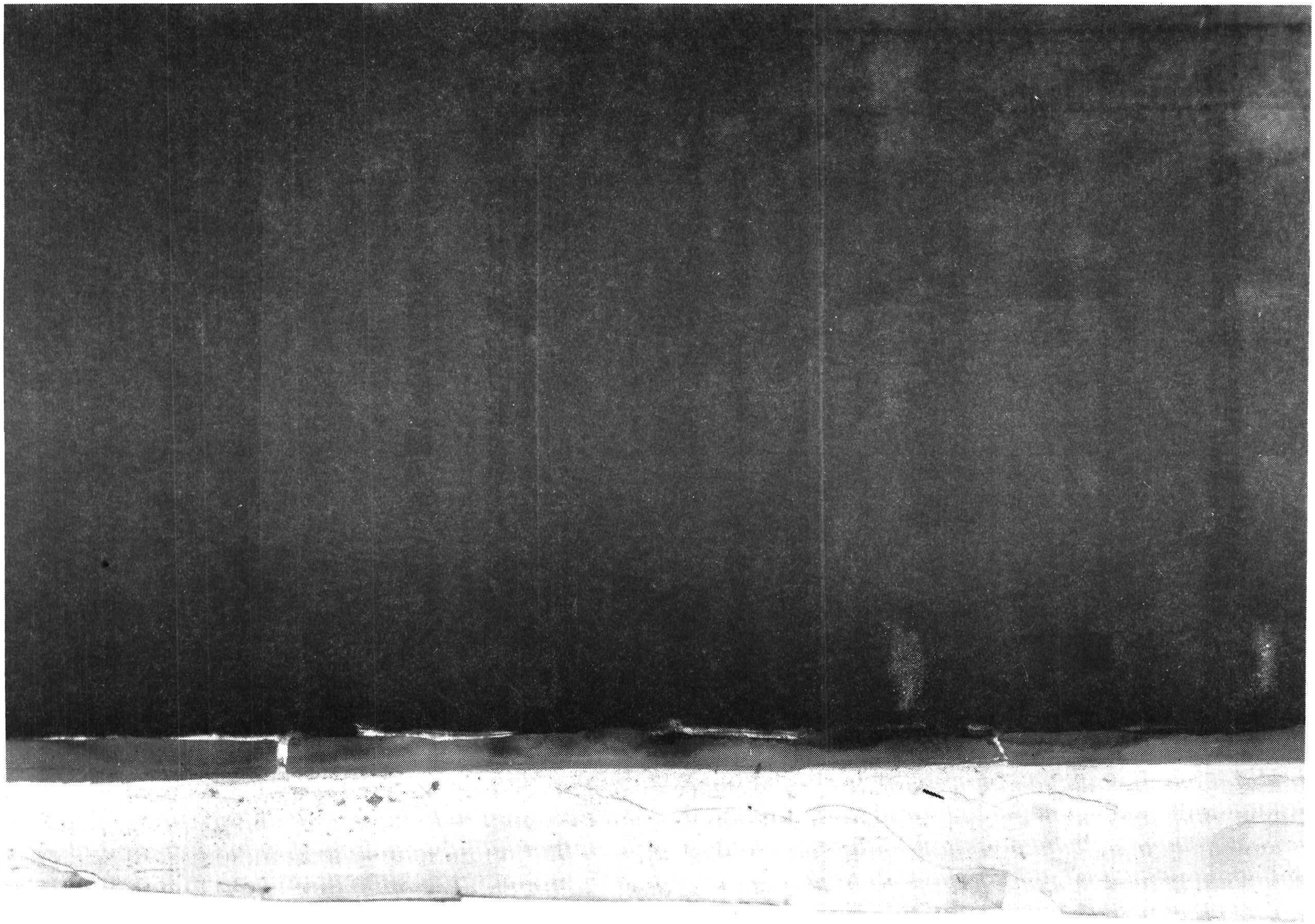


Figure 41- Cylindrical Panel Cold Joint Failure

This again points to the need for better control of the adhesive joint thickness to fabricate functional panels.

Several conclusions were drawn from these two system cycling tests. First, the 300 S Mylar polyester/RTV system can withstand a cyclic 300°F (177°C) external temperature environment. However, a more accurate control of adhesive thickness appears to be required to overcome brittleness problems in the cold joint. Panel-to-panel seals can be made reliably with 732 RTV adhesive. Overall, the 300 S Mylar polyester/732 RTV system appears to have potential for acceptable mechanical performance for the Shuttle application.

4.4 Full Scale Insulation System (Task III, V)

4.4.1. Full Scale Insulation System Design

As noted in the discussion of Shuttle System Vehicle Requirements, the shuttle configuration has not been finalized. However, within a limited framework, certain design conditions will be encountered regardless of the final configuration, i.e. whether the final tankage is spherical, elliptical or cylindrical, or combinations of these. Many of the problems will be common to those of the assumed design.

As shown in Figure 42 , a 15 foot (4.6m) diameter vessel having hemispherical heads and 3 foot (0.9 m) long cylindrical section has been assumed for the full scale shuttle vehicle design. The vessel was sized to achieve the required 2300 ft^3 (65.1 m^3) (Ref. Table 1) volume. The resulting tank has a surface area of 848 ft^2 (78.8 m^2) and an L/D ratio of 1.2. Penetrations indicated in Figure 41 include the following:

1. 0.5" (1.3 cm) diameter GH_2 line
2. 1.25" (3.2 cm) diameter LH_2 line
3. 4.0" (10.2 cm) diameter LH_2 line
4. Single point strut support system (composed of 4 groups of 2 struts per group)

The support system, to be realistic was sized to provide for a total loading of 15,000 lb (6810 Kgm) consisting of an insulated tank and 10,000 lbs. (4540 Kgm) of LH_2. Design acceleration loadings of 8.5 g in tension, and 3.5 g compression were considered. Assuming an 18 inch (45.7 cm) long fiberglas strut with metal support cap ends per current technology*, a wall thickness of 0.1 inch (2.5 mm) for a 1.75 inch (4.4 cm) diameter strut was determined acceptable for these loadings.

* * * * * * * * *

* Purpose of this calculation was to obtain an approximate size of support for thermal load calculations only. They do not imply a design for structural purposes.

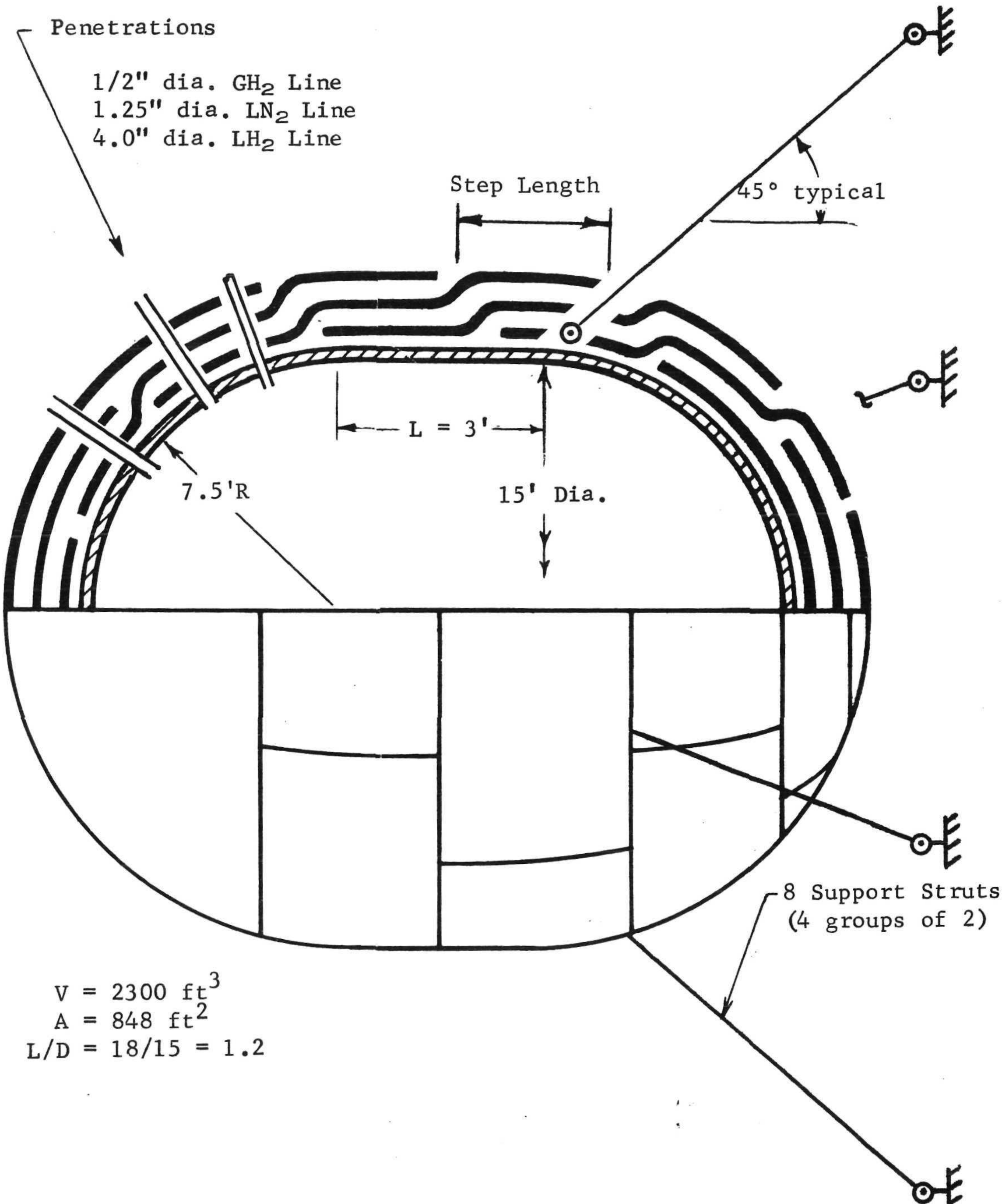


Figure 42 Assumed LH_2 on-orbit tank including support and penetrations

For estimation purposes it was assumed the support rod was thermally isolated from the surrounding insulation so that there was no interaction between the support rod and insulation to alter the one dimensional temperature distribution in the rod. A one-dimensional heat transfer analysis was used to estimate the heat leak for these 8 struts operating between 810°R (450°K) and 36°R (20°K). The resulting heat leak through these support rods was determined to be 25 BTU/Hr (7.32 watts). Actual heat leak will be less since the 810°R (450°K) is a transient condition. Assuming an insulation heat flux of 0.63 BTU/Hr - Ft^2 (1.99 watt/m^2) achieved for the 18 shield 3 panel system of NAS 3-7953 (see Reference 2, Appendix 2) yields an estimated thermal performance for insulation and supports of about 560 BTU/Hr (164 watts).

The effect of panel thickness and total number of radiation shields, as well as panel length and conductivity were evaluated. The analysis uses the data derived from the calorimeter testing and computer analysis of a previous UCC contract (NAS-3-7953) as reported in CR 72363 (Reference 2) where the insulation's heat flux was determined to be .63 BTU/Hr-ft^2 (1.99 watts/m^2). By applying ratios to the many variables and finally totalizing to arrive at a new system heat flux for the stated conditions, the effects of the various panel variables was shown. All panel systems assume the same spacer configuration.

The ratios used included the following:

<u>Radiation</u>

Ratio to relate effect of number of shields $= \dfrac{N + 1}{(N_x + 1)} (Q/A)_R$

N is number of shields, and N_x was number of shields used to obtain the stated $(Q/A)_R$ (radiation heat flux).

<u>Temperature Effects</u>

Ratio of boundary temperatures to the fourth power.

<u>Lateral Heat Flow</u>

As a first approximation, ratios of operating temperatures and panel lengths were applied. Casing, spacer, and shield mean thermal conductivities were assumed constant for any one set of temperatures.

<u>Normal Heat Flow</u>

The sum of the radiation heat flow and lateral heat flow was subtracted from the total system heat flow and lumped into a term called normal heat flow.

These ratios when applied to the data obtained on previous contract efforts will merely provide an approximate solution to a complex problem. An exact solution would involve an extensive analysis to include

such variables as casing shield and spacer thermal conductivity variations with temperature and pressure as well as appropriate boundary conditions. For our present purposes this rather approximate approach will give sufficient data to allow estimates of system thermal performance under various geometrical configurations. However, any final system design should include a more rigorous analysis.

Data from the scaling analysis is summarized in Table 14 and Figure 43 .

The indicated performance of the SEMI system operating at a service temperature of 810°R (450°K) is strictly an estimate and a reference point for comparison. The 810° case is only of short duration during a transient condition. In addition, the SEMI system would likely be undergoing a one atmosphere compression which would alter the thermal performance considerably.

Various panel system designs were evaluated as indicated in Table 15 . Variables included the number of panels and overall panel dimensions which affect the total number of SEMI panels required and the heat flux. A computer analysis was not performed to predict the heat flux for each system, but rather the thermal performance was estimated by scaling data as discussed previously. All systems were designed for the assumed on-orbit LH_2 tank (see Figure 42). The design consisted of circumferential panels and polar panels. The system except for panel sizes is the same as discussed in the previous SEMI panel contracts. Variations include the width of the polar panel segments used to insulate the spherical tank heads, the length of the panel step (shingle length) for both polar panels and circumferential panels, and the width of circumferential panels used to insulate the cylindrical portion of the tank. The dimension of width is assigned to the dimension of the step parallel to the cryopump direction. A summation of panel widths equal the circumference of the tank for that location. In other words, each panel at the straight cylindrical section has a panel width equal to the circumference divided by 12 for a 12 panel width system.

Table 15 lists panel width variations for 3, 6 and 12 panel systems as well as overall panel length variations using 9, 10, 12 and 14 step systems. For a circumferential panel, the total panel length is equivalent to three times the step length. The step length of the circumferential panel and the step length of the polar panels are equal. The panels were assumed to constitute a zero thickness, therefore simplifying the panel layout. The actual error in doing this amounts to less than 2% of the panel dimensions because of the relative panel thickness to panel length ratio.

For the full size on-orbit tank a SEMI panel system consisting of a 10 step-12 panel width configuration (10 panels required to span tank length and 12 panels to go around tank circumference) was chosen. This results in panel dimensions of approximately 4' x 8' (1.2 m x 2.4 m) which from previous investigations appears to offer a workable size and good thermal performance. The insulation system layout including approximate panel sizes is included in Figure 44. A total of 96 panels are required to insulate the assumed LH_2 tank.

TABLE 14

Data - Heat Flux vs. Panel Variables

Total System Radiation Shields	Panel* System	Q/A Radiation	Q/A Lateral						Q/A Normal	Q/A Total Heat Flux		
			Casing Length			Shield Length						
Panel length (ft.) →			4	6	8	4	6	8		4	6	8
Δt = 520°R - 36°R												
12	5/4	.102	.21	.140	.105	.019	.013	.009	.56	.89	.82	.77
15	6/5	.083	.21	.140	.105	.026	.016	.012	.48	.80	.72	.68
Base Case 18 (NAS 3-7953)	7/6	.07	.21	.140	.105	.030	.020	.015	.40	.71	.63	.59
21	8/7	.06	.21	.140	.105	.034	.023	.017	.35	.65	.57	.53
24	9/8	.053	.21	.140	.105	.39	.026	.020	.31	.61	.53	.49
27	10/9	.050	.21	.140	.105	.045	.029	.022	.28	.59	.50	.46
54	19/18	.020	.21	.140	.105	.089	.059	.044	.14	.46	.36	.31
Δt = 810°R - 36°R												
12	5/4	.593	.330	.224	.168	.031	.018	.016	.89	1.84	1.73	1.67
15	6/5	.483	.330	.224	.168	.039	.026	.018	.76	1.61	1.49	1.43
18	7/6	.402	.330	.224	.168	.048	.032	.024	.64	1.42	1.30	1.23
21	8/7	.348	.330	.224	.168	.048	.032	.024	.56	1.29	1.16	1.11
24	9/8	.308	.330	.224	.168	.072	.048	.036	.50	1.21	1.08	1.01
27	10/9	.291	.330	.224	.168	.072	.048	.036	.45	1.14	1.01	.95
54	19/18	.116	.330	.224	.168	.140	.096	.072	.22	.81	.66	.58

* Panel System - 5/4 Refers to 5 Foam Composite Spacers (Style PT-6), 4 Radiation Shields.

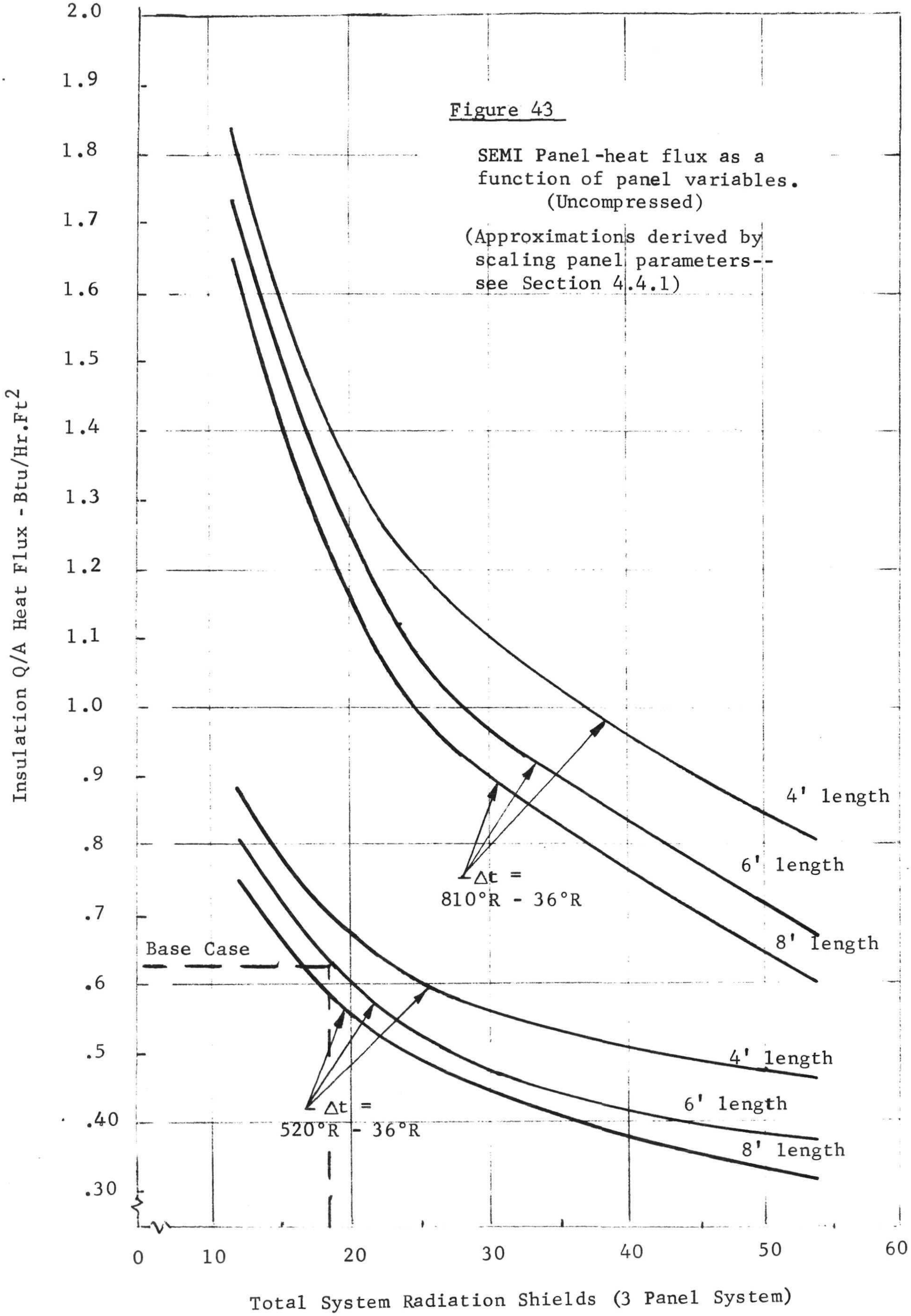


Figure 43
SEMI Panel-heat flux as a function of panel variables. (Uncompressed)
(Approximations derived by scaling panel parameters--see Section 4.4.1)
Insulation Q/A Heat Flux - Btu/Hr.Ft^2
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.40
.30
4' length
6' length
8' length
Δt = 810°R - 36°R
Base Case
4' length
6' length
8' length
Δt = 520°R - 36°R
0
10
20
30
40
50
60
Total System Radiation Shields (3 Panel System)

TABLE 15

SUMMARY - Panel System Configuration for The Full Size LH_2 On-orbit Tank

A. Circumferential Panel Systems

System	Maximum Overall Panel Width (Feet)			Overall Length (Feet)
	3*	6*	12*	
9 Step**	15.7	7.85	3.93	9.0
10 Step	15.7	7.85	3.93	8.0
12 Step	15.7	7.85	3.93	6.6
14 Step	15.7	7.85	3.93	5.7

B. Polar Panel System

Panel System	Overall Panel Dimensions (Feet)					
	3*		6*		12*	
	12.6	13.3	6.9	10.6	4.6	8.0

* Refers to number of panels around the tank circumference.

** Refers to number of different panel width dimensions required.

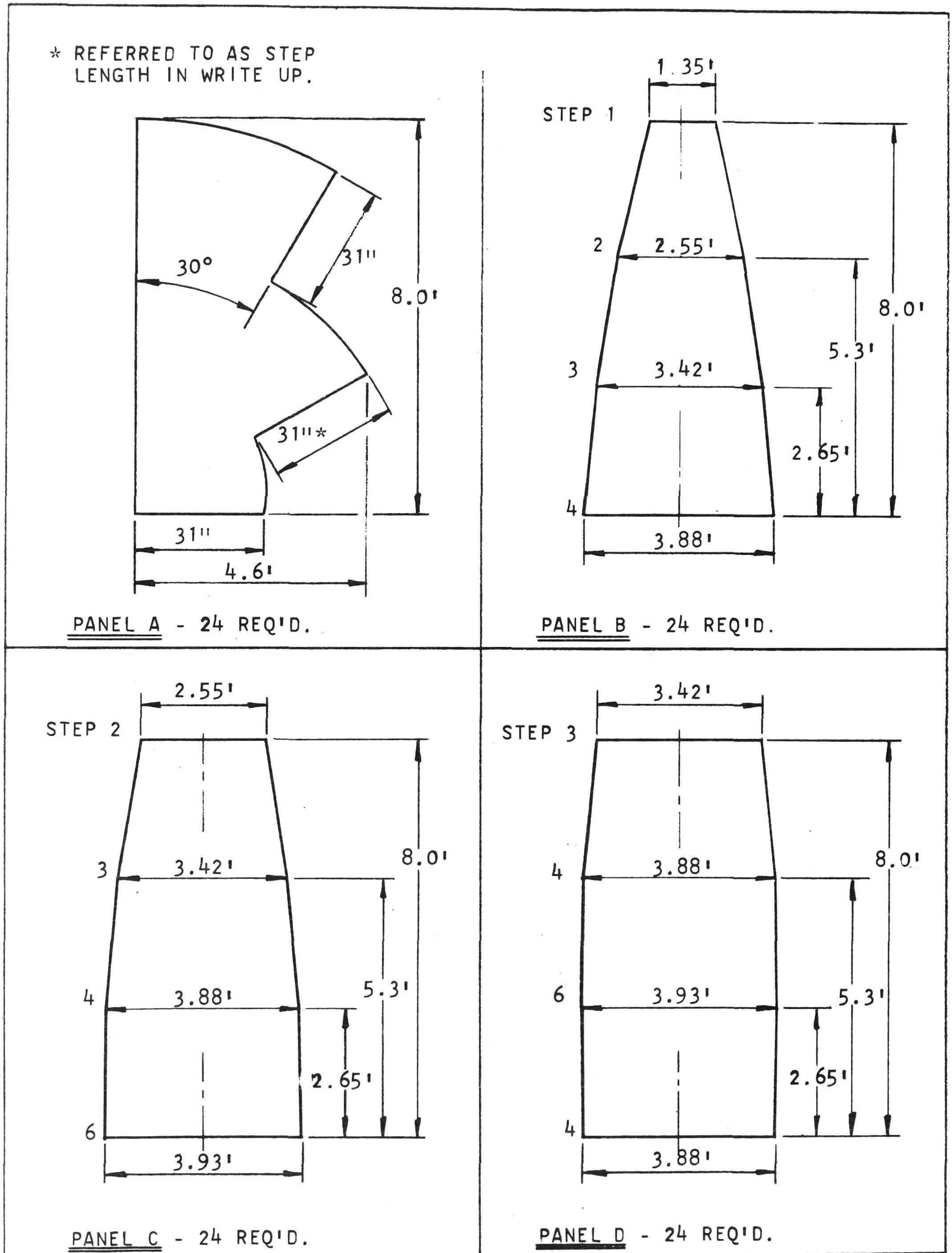


Figure 44 12 Panel System for Full Size Tank

Thermal performance for the polar panels in the full scale design was estimated by a geometric scaling of a computer analysis of a previous contract effort. From observations of Table 1 and Figure 3 of NASA CR-72856, polar head panels having a 21" (53.3 cm) shingle length (Step) for a 10' (3.05 m) diameter tank contribute the following heat flux:

System	Heat Flux
3 Panel	.54 BTU/Hr-Ft^2 (1.70 watts/m^2)
6 Panel	.61 BTU/Hr-Ft^2 (1.92 watts/m^2)
12 Panel	.82 BTU/Hr-Ft^2 (2.59 watts/m^2)

From Table 2 of the same report, a 3 polar panel insulation system for the model tank exhibited a heat flux of 2.5 BTU/Hr-Ft^2 (7.89 watts/m^2) using a 4" (10.2 cm) step length. The ratio of heat fluxes appears to be approximately equal to the reciprocal of the ratio of heat path lengths (step lengths) i.e. 4" to 21" (10.2 - 53.3 cm) or .45 to 2.5 BTU/Hr-Ft^2 (1.42 - 7.88 watts/m^2). For preliminary design calculation purposes, it was assumed that the present system designed for the 15 ft (4.57 m) diameter full size tank with a 31" (78.7 cm) step length (see Figure 44 Panel A) will exhibit a performance of 21/31 or 68% of the heat flux of the 12 panel insulation system used on the 10 ft (3.05 m) diameter tank. The expected performance for the polar panels on a tank should be 21/31 x .82 or .55 BTU/Hr-Ft^2 (0.17 watts/m^2) for the 12 panel system. This approximation is valid only if the ratio of panel normal area to step length remain about the same.

For the circumferential panels, the thermal performance achievable should approach the performance achieved in the cylindrical portion of the 10 ft (3.08 m) diameter tank or the performance achieved in the calorimeter tank which was approximately 0.6 BTU/Hr-Ft^2 (0.19 watts/m^2). This also agrees with a calculated heat flux of 0.6 BTU/Hr-Ft^2 (0.19 watts/m^2)developed in Table 14 for 8 ft (2.4 m) long SEMI panels. Using this value of heat flux and the polar panel heat flux previously discussed to calculate the performance of the circumferential panels for the assumed LH_2 on-orbit shuttle tankage, indicates the insulation performance for the design as shown in Figure 44 of this report as 471.2 BTU/Hr (1485.4 watts/m^2). This calculated performance is slightly better than predicted in Figure 43 because of the larger panel sizes assumed in this design.

The Insulation Thermal Performance was calculated as follows:

Head Area

Both ends

$$\text{Area} = D^2 = 3.14\,(15)^2 = 707 \text{ ft}^2 \; (65.7 \text{ m}^2)$$

$$\text{Performance} = 707 \times .55 = 388 \text{ BTU/Hr} \; (1223.2 \text{ watts/m}^2)$$

Cylindrical Area

$$A = D\,L$$
$$= 3.14\ (15)\ (3.0)$$
$$= 141\ ft^2\ (13.1\ m^2)$$

Performance - 141 x .59 = 83.2

or Total Insulation Performance 388

83.2

471.2 BTU/Hr (1485.5 watts/m^2)

Heat flux values obtained from previous contract efforts all are based on a temperature differential of 530-37°R (294 - 20°K). For approximation purposes these values were used rather than values at an upper temperature of 840°R as this high temperature exposure is of relatively short duration.

4.4.2. Large Scale Insulation Design

A preliminary design of a large scale model system of the proposed on-orbiter hydrogen tankage was initiated. This design was to form the basis for a large scale test of the insulation system discussed in the previous section. Although the hardware and panels were not fabricated due to a shift in program emphasis, the results of the design effort to date are included in this report for the sake of completeness. However, the design calculations and drawings presented in this section are incomplete and unchecked, and Union Carbide Corporation assumes no responsibility for actions resulting from construction and testing based on them.

The model system (Task V) is a subscale model of the full size on-orbiter hydrogen tankage and would be 4' (1.2 m) in diameter by 6' (1.8 m) in length with hemispherical heads. Panel sizes for the subscale tank are similar to panel sizes encountered on the large tank. Support rods for the subscale tank, must be shorter than the support rods for the full scale on-orbiter tank, to allow the subscale system to experience the same angular movement (4.3°) as expected on the full scale support systems. Consequently, penetrations designed and tested on the subscale system will be directly applicable to the on-orbiter (full size) design. To achieve an angular movement in the support rod of 4.3°, requires support rod lengths of 7" (17.8 cm) and 3.4" (8.6 cm) for the 6 foot (1.8 m) and 4 foot (1.2 m) tank dimensions respectively. The design of the subscale tank and transporter is shown in Figures 45 and 46. However, the very short support rods may prove physically impossible to achieve, and therefore it may not be practical to simulate the desired angular movement of the full size shuttle tank on the subscale tank.

Design calculations for the TASK V vessel are included in Section 6.5. The vessel is four feet (1.2 m) in diameter and six feet (1.9 m) in length, incorporating hemispherical heads. It has been designed to withstand internal pressurization to 75 psi (5.17×10^5 N/m^2) which may result from pressure build-up due to cryogen boil-off during

testing as well as 15 psi (1.03×10^5 N/m^2) external pressure which will be present during evacuation for leak checking. The tank will be suspended from a frame which will function both as a transporter to the test site, and as a handling cart during testing. The frame as shown in Figure 46, will be mounted on casters to allow easy manipulation. The frame has been designed to withstand a 5g shock loading in three mutually perpendicular directions. Design calculations for the transporter are shown in Section 6.6.

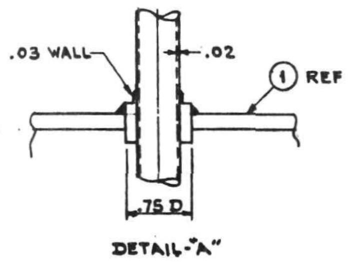
The subscale insulation system will consist of 18 total panels, i.e. 6 polar and 12 cylindrical (see Figure 47). The polar caps will be 3-panel systems, while the cylindrical portion of the tank will utilize a six panel shingled system. In addition each cylindrical panel will be fabricated in two pieces (panel A and D, and B and C as shown on Page 2 of Figure 47) to allow easier handling and fabrication. The seam where the two panels meet will be staggered (i.e. shifted about 12 inches, .31 m) to prevent a straight line heat path through the insulation.

Each insulation panel will consist of 7 spacers and 6 shields, for a 3-panel system of 18 shields. Each spacer will combine punched foam and Dexiglas as in the Task IV panels. The shields will also combine aluminized Mylar and aluminized Kapton. Dow Corning 732 RTV adhesive will be used for all panel joints.

Thermal performance for the polar panels was determined by the method discussed earlier, i.e. estimation using a geometrical scaling of a computer analysis for a previous contractural effort. From observations of Table I and Figure 3 of NASA CR-72856 (Reference 3), a 3-panel system having a 21 inch (53.3 cm) shingle length for a 10 foot (3.05 m) diameter tank contributes a heat flux of 0.54 BTU/Hr-Ft^2 (1.7 watts/m2). From Table II of the same report, a 3-polar panel system for the model tank exhibits a heat flux of 2.5 BTU/Hr-Ft^2 (7.88 watts/m^2). It is likely, therefore, that the present system designed for the 4 foot (1.2 m) diameter tank with an 8 inch (20.3 cm) step (see Page 2 of Figure 47), will exhibit a performance of 21/8 or 2.63 times the heat flux of the 3 panel system used on the 10 foot (3.05 m) diameter tank. The expected performance for the polar panels on the tank is therefore $21/8 \times 0.54 = 1.43$ BTU/Hr-Ft^2 (4.51 watts/m^2).

For the circumferential panels, the thermal performance achievable should approach the performance observed for the cylindrical portion of the 10 foot (3.05 m) diameter tank, or the performance of the calorimeter tank which was 0.6 BTU/Hr-Ft^2 (1.89 watts/m^2). This agrees with the calculated heat flux of 0.6 BTU/Hr-Ft^2 (1.89 watts/m^2) developed in Figure 43 for 8 foot (2.4 m) long SEMI panels. However, since Task V panels will be only 6 feet (1.8 m) long, Figure 43 suggests the expected thermal performance for the cylindrical panels should be 0.65 BTU/Hr-Ft^2 (2.05 watts/m^2). Using this value of heat flux to calculate the performance of the circumferential panels indicates the insulation performance for the design of Figure 47 is approximately 87.6 BTU/Hr-(276.2 watts/m^2).

TOLERANCES UNLESS OTHERWISE NOTED:
.X = ±.1, .XX = ±.06, ANGULAR ± °
MACHINED SURFACES SHALL BE √



U/M	ITEM NO.	LINDE PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION		DWG. ALT. LETT.
	1		1	PLATE .1875 X 23.62 X 151.38 H.R. ANNEALED & PICKLED ASME SA-240 TYPE 304 STAINLESS STEEL.		
	2		2	HEAD, HEMISPHERICAL, 48 I.D. X .1875 THK. NOM., NO S.F. 24 INSIDE RAD., 24.19 OAH. .062 NOSE		
				30° BEVEL, ASME SA-240 H.R. ANNEALED & PICKLED AFTER FORMING TYPE 304		
				STAINLESS STEEL.		
	3		1	PIPE 2 SCH 40S X 6.5 LG. TYPE 304 STN STL.		
	4		1	TUBING, .50 O.D. X .020 WALL X 51.19 LG, TYPE 304 STAINLESS STEEL.		
	5		4	ROD THREADED .75-10 UNC-2A X .88 LG, CONTINUOUS, AISI TYPE 304 STAINLESS STEEL.		

NOTE - Calculations And Drawings Unchecked. UCC-Linde Accepts No Responsibility For Actions Resulting From Construction Or Testing Based On Them.

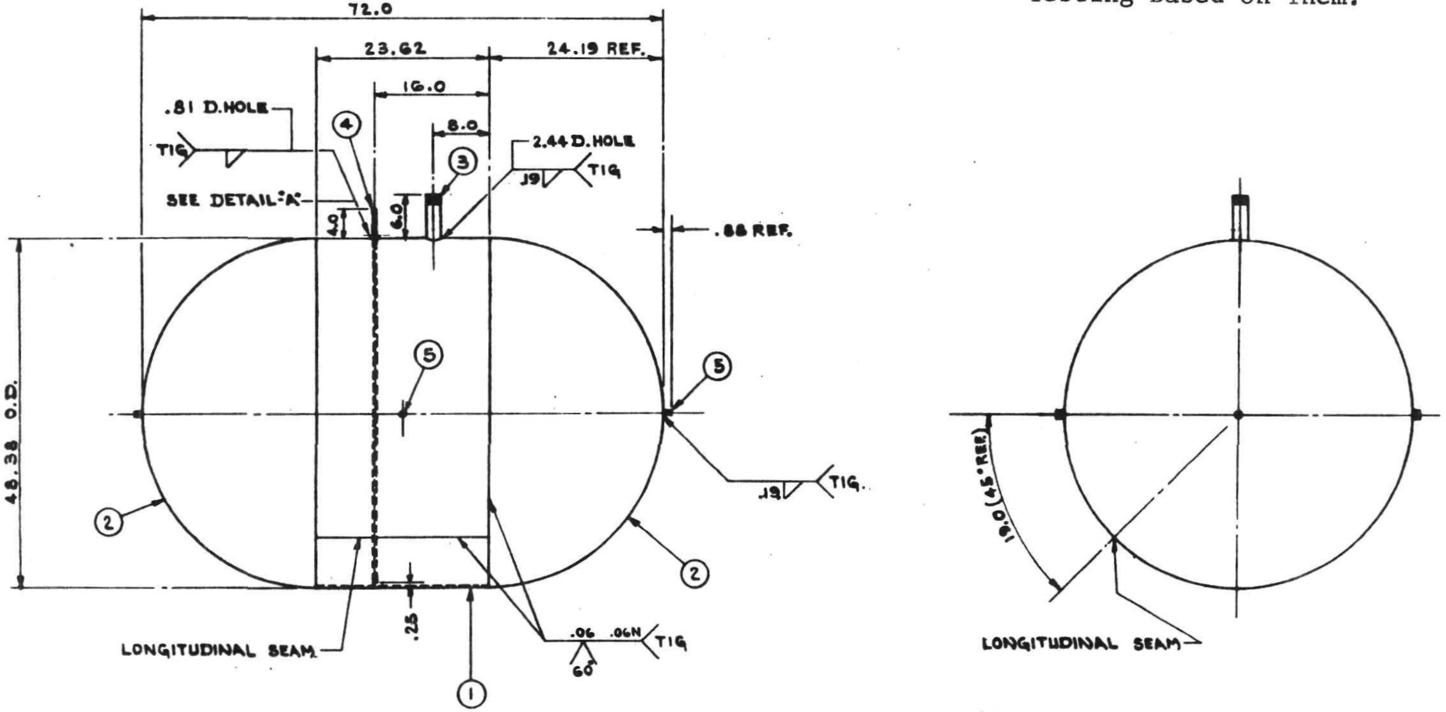


Figure 45 - Subscale Tank Design

TITLE: TASK VI LH$_2$ TEST VESSEL
NASA LEWIS
CONTRACT NAS 3-14366

UNION CARBIDE CORPORATION
LINDE DIVISION
TONAWANDA, NEW YORK

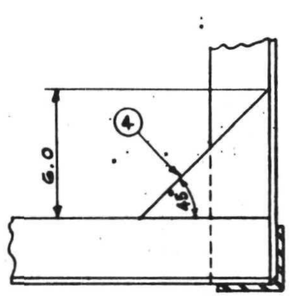
BY NJD DATE 2-23-72 SCALE 1" = 1'-0"

C/SK-108534

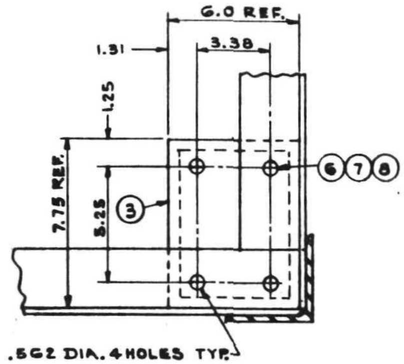
C/SK-108535

FIRST USED ON ASSEMBLY NO.

TOLERANCES UNLESS OTHERWISE NOTED: .X = ±.1, .XX = ±.06, ANGULAR ± °
MACHINED SURFACES SHALL BE √

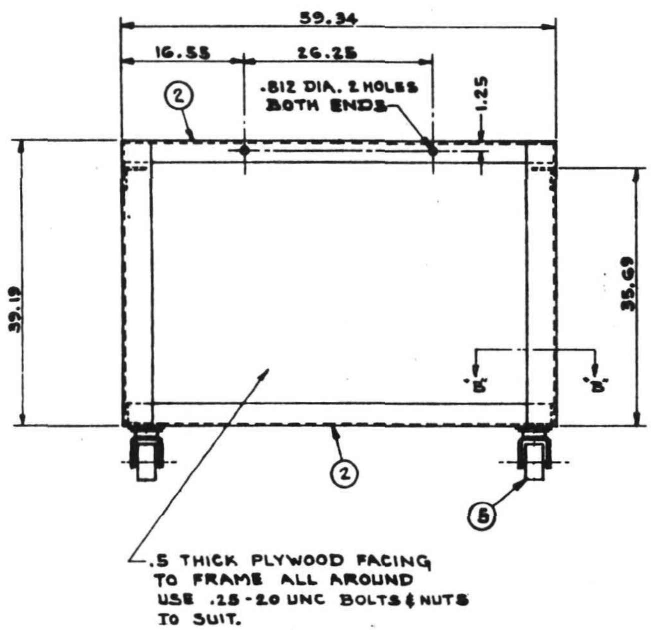


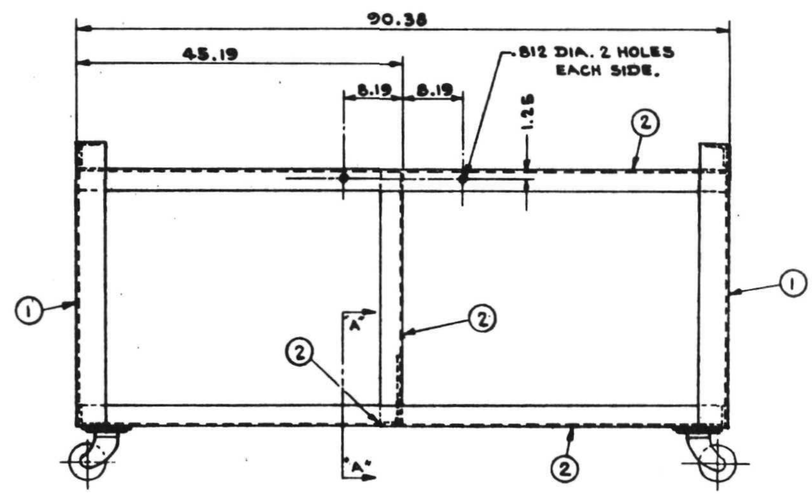
SECTION "A-A"
SCALE 3" = 1'-0"



SECTION "B-B"
SCALE 3" = 1'-0"

U/M	ITEM NO.	LINDE PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION		DWG. ALT. LETT.
IN	1	1180-2835	1	ANGLE 4X4X.25X158LG STEEL.		
IN	2	1180-2555	1	ANGLE 3X3X.25X674 LG STEEL.		
	3	1188-0795	4	PLATE .25 X 6 X 7.75 STEEL.		
	4	1188-0795	1	PLATE .25 X 6X6 (MAKES 2) STEEL.		
	5		4	CASTER, SEMI-STEEL, BASSICK N°S5991-2		
	6	4043-5126	16	SCREW, .5-13 UNC X 1.25 LG., CAP HEX HD. CADMIUM PLATED, STEEL.		
	7	4016-4675	16	NUT, .5-13 UNC, HEAVY SEMI-FIN. ZINC OR CADMIUM PLATED, STEEL.		
	8	4075-3025	16	WASHER .5 MEDIUM LOCK CADMIUM PLATED STEEL.		





NOTES:
1-ALL CONSTRUCTION TO BE METAL ARC WELD FULL FILLET ALL AROUND, WHERE POSSIBLE.
2-COPE TO SUIT.

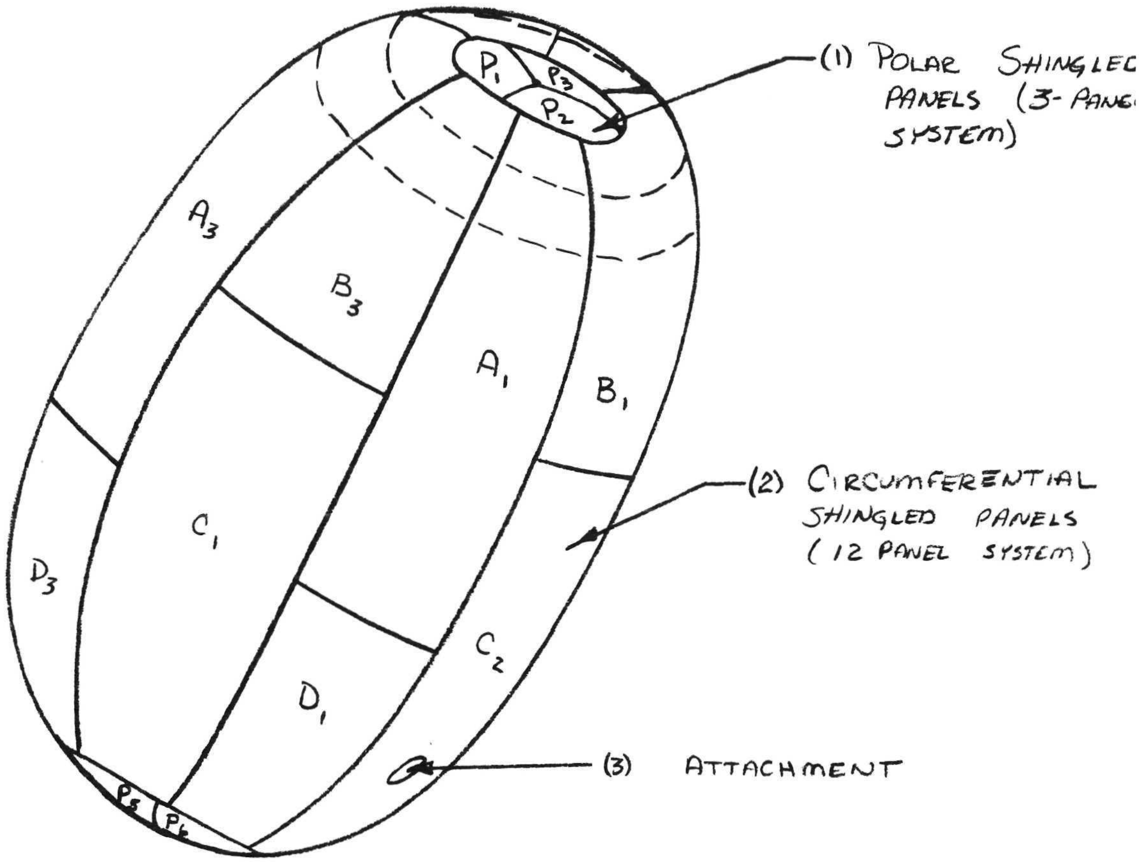
Figure 46 - Subscale Tank Transporter Design

NOTE - Calculations And Drawings Unchecked.
UCC-Linde Accepts No Responsibility
For Actions Resulting From Construction
Or Testing Based On Them.

TITLE: TASK VI TANK TRANSPORTER NASA LEWIS CONTRACT NAS 3-14366	SIMILAR TO
	BY NJD DATE 2-24-72 SCALE 1" = 1'-0"
	CHECKED — SH. NO. 1
UNION CARBIDE CORPORATION LINDE DIVISION TONAWANDA, NEW YORK	APPROVED — NO. SH. 1
	C/SK-108535

LETT. | ALTERATION | DATE | BY | CHK'D | APPV'D | LETT. | ALTERATION | DATE | BY | CHK'D | APPV'D | LETT. | ALTERATION | DATE | BY | CHK'D | APPV'D

LARGE SCALE SHINGLED INSULATION SYSTEM FOR LIQUID HYDROGEN TEST VESSEL (TASK V)



TANK DIAMETER - 4 FEET

TANK LENGTH - 6 FEET

POLAR PANELS REQ'D - 6

CYLINDRICAL PANELS REQ'D - 12

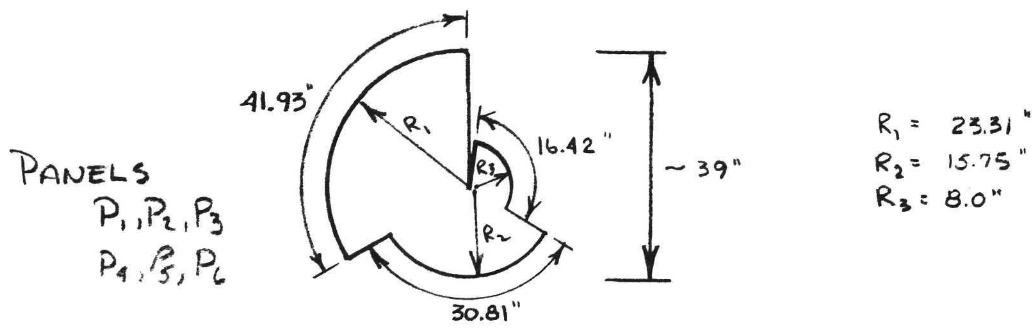
Figure 47

Insulation System - Task V Vessel

Contract No. NAS 3-14366

Sheet 1 of 5

(1) POLAR SHINGLED END PANELS (3-PANEL SYSTEM) : 6 REQ'D



(2) CIRCUMFERENTIALLY SHINGLED OUTER PANELS (6-PANEL SYSTEM): 12 REQ'D

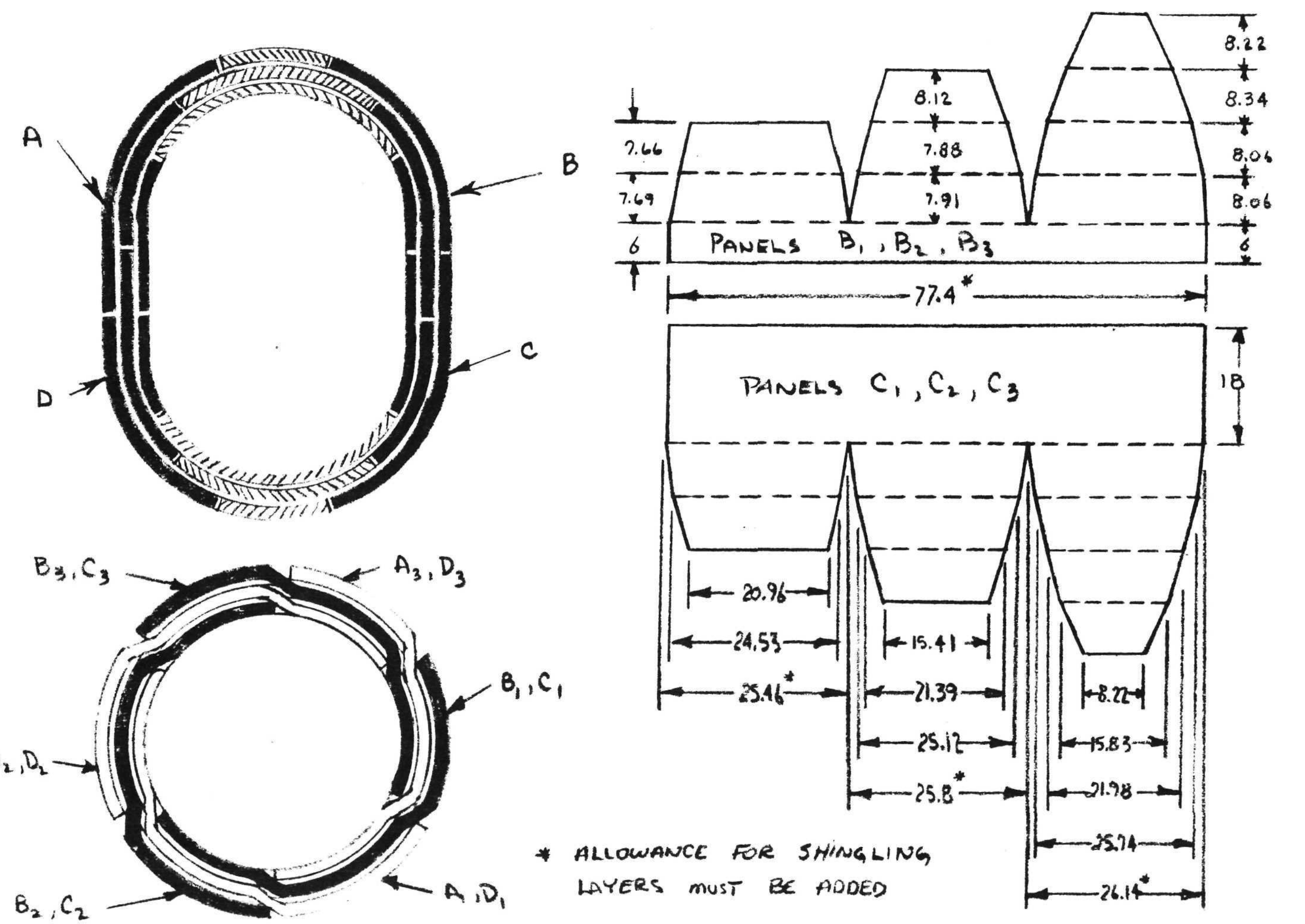


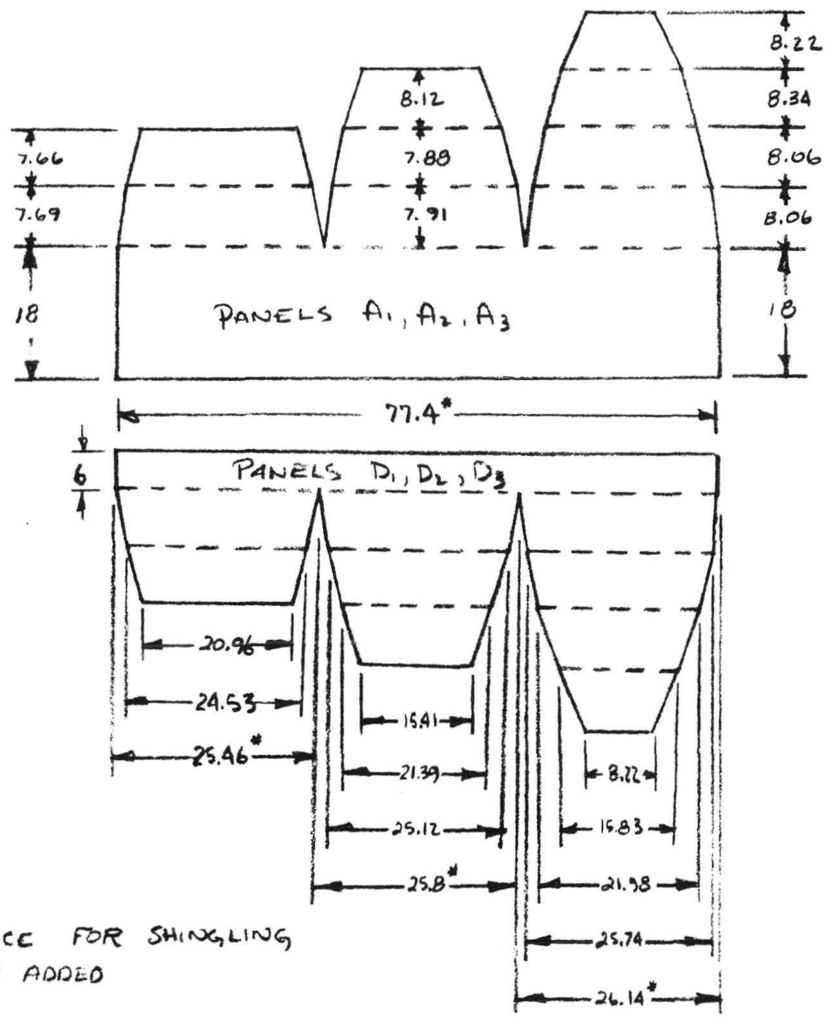
Figure 47

Insulation System - Task V Vessel

Contract No. NAS 3-14366

Sheet 2 of 5

(2) CONTINUED



* ALLOWANCE FOR SHINGLING MUST BE ADDED

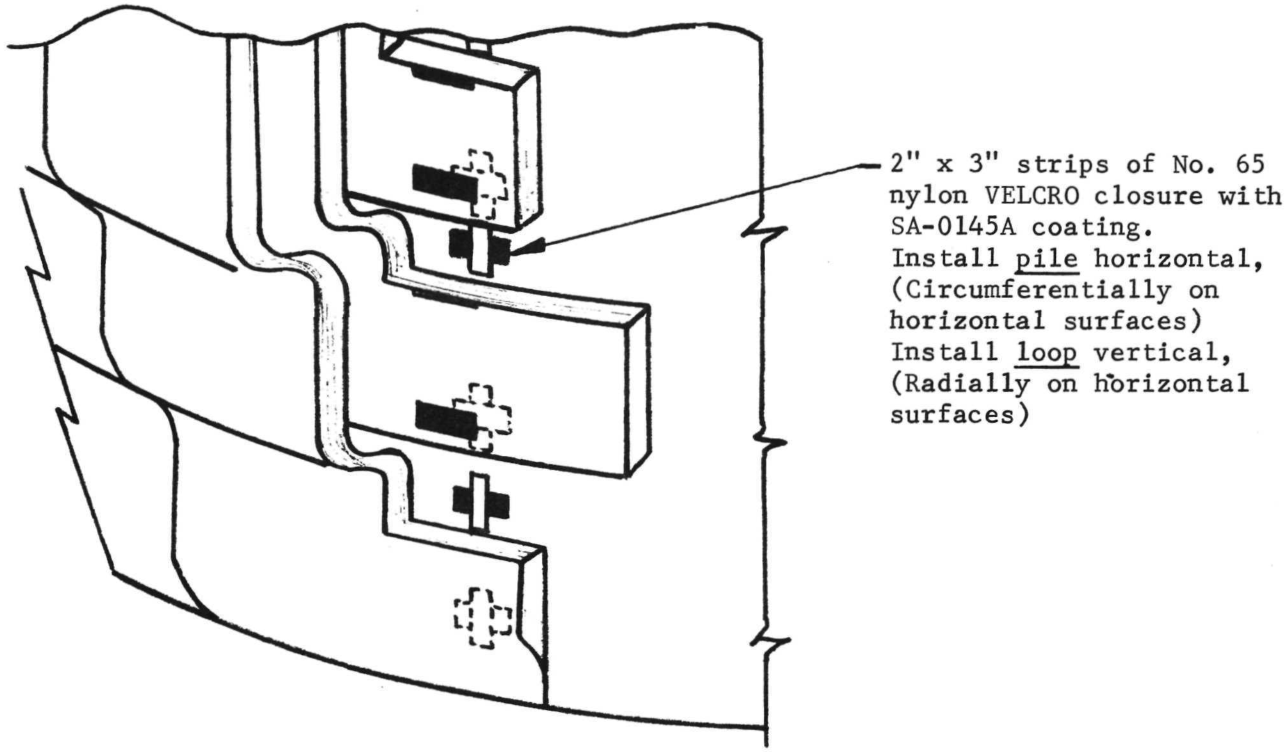
Figure 47

Insulation System - Task V Vessel

Contract No. NAS 3-14366

Sheet 3 of 5

(3) Attachment (VELCRO) Typical



ASSEMBLY NOTES:

1. VELCRO to be located on each panel in such a pattern that each square foot of insulation panel contains 4 in^2 of VELCRO closure.

2. Distance from closest edge of VELCRO attachment to edge of panel to be 2" $\pm$ 1/4".

3. Surface to be wiped with methyl ethyl ketone (MEK) and allowed to air dry, prior to placing VELCRO. VELCRO adhesive backing to be re-constituted with a single MEK wipe, and allowed to become tacky (approximately 3 minutes) before positioning. Adhesive will air cure at ambient temperatures and pressure in 24 hours. Stainless steel surfaces should be MEK wiped, abraided with a wire brush, and then rewiped with MEK and air dried prior to placing VELCRO as previously described.

Figure 47

Insulation System - Task V Vessel

Contract No. NAS 3-14366

(3) CONTINUED, VELCRO PLACEMENT (BACKSIDE)

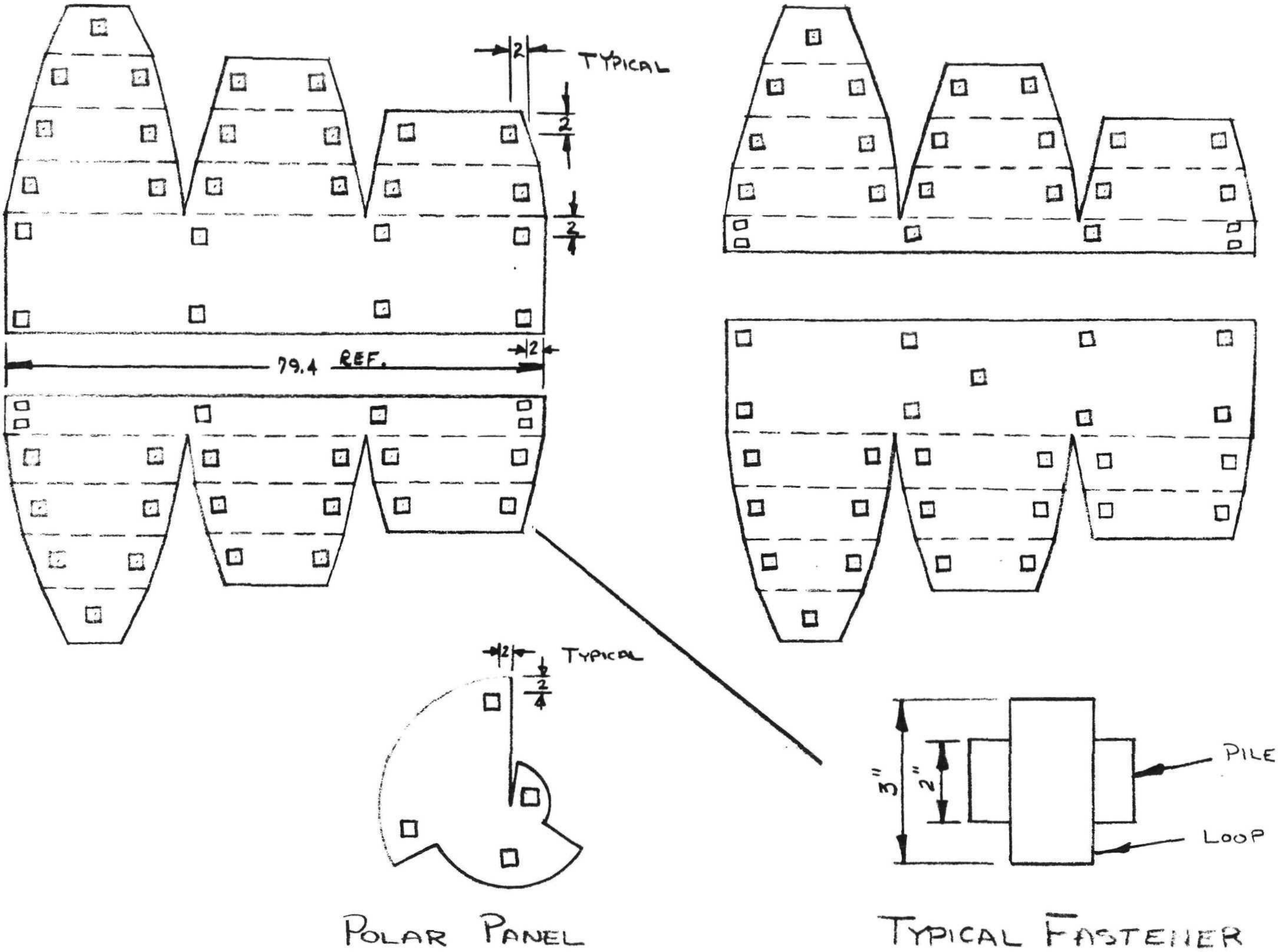


Figure 47

Insulation System - Task V Vessel

Contract No. NAS 3-14366

Sheet 5 of 5

The thermal performance was calculated as follows:

Head Area

Both ends
Area = D^2
= $(3.13)\ (4)^2$
= $50.24\ ft^2\ (4.67\ m^2)$
Performance = $(50.24)\ (1.42)$
= 71.3 BTU/Hr. (224.8 Watts/m^2)

Cylindrical Area

Area = DL
= $(3.14)\ (4)\ (2)$
= $25.12\ ft^2\ (2.53\ m^2)$
Performance = $(25.12)\ (0.65)$
= 16.3 BTU/Hr. (51.4 Watts/m^2)
or the total insulation performance = 71.3
16.3.
87.6 BTU/Hr. (276.2 watts/m^2)

4.4.3. Large Scale SEMI Panel Fabrication

The purpose of this task was to demonstrate that a large scale panel could be fabricated using the handling and forming experience previously developed during this contractual effort. A large size (6-1/2 feet x 3 1/4 feet, 2 m x 1 m) cylindrical panel with penetration areas from the Task V subscale insulation design was built (see Figure 47, page 2 of 5).

The large scale panel consisted of the previously qualified 3 mil (.076 mm) 300 S Mylar polyester film bonded with Dow Corning 732 RTV adhesive. The panel contained seven layers of Dexiglas mat to maintain its thickness. The casing was formed using the technique described earlier for the subscale cycling test panels. The 3 mil (.076 mm) polyester casing material was stretched across a wooden female vacuum mold. Evacuation of the form forced the casing down into the form. A heat gun was then used to provide the localized heating necessary to obtain additional casing stretch and set. A picture of the drawn casing on the stretching form is shown in Figure 48. Two penetration areas and three evacuation ports were included in the panel design. The penetration areas had a 3 1/4 inch (8.3 cm) inside diameter as on previous panels. These penetration areas were formed separately using an aluminum male mold. The polyester film was stretched over the form and the form placed in an oven at 400°F (204°C). After a short wait to allow the casing to reach temperature, the form was evacuated forming the small cup shape necessary for the penetration area. The casing was then allowed to cool to ambient temperature and trimmed prior to installation. Penetration area "cups" were bonded to the main body casing using 732 RTV adhesive. In addition, a thin nylon mesh was placed in these joints to minimize any tearing in these regions as encountered with the Kapton/RTV system. The completed panel is shown in Figure 49.

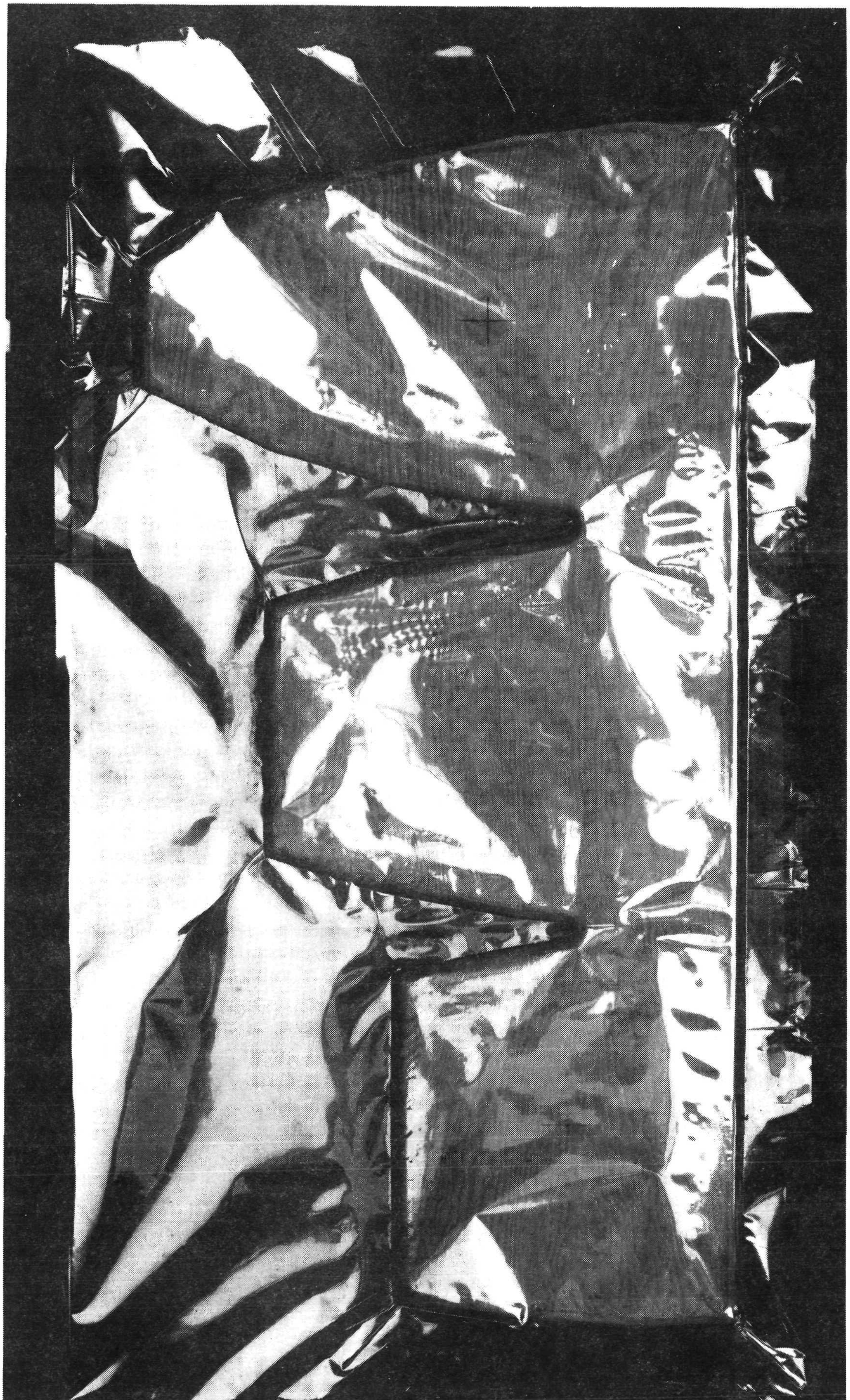


Figure 48 - Large Scale Panel Casing

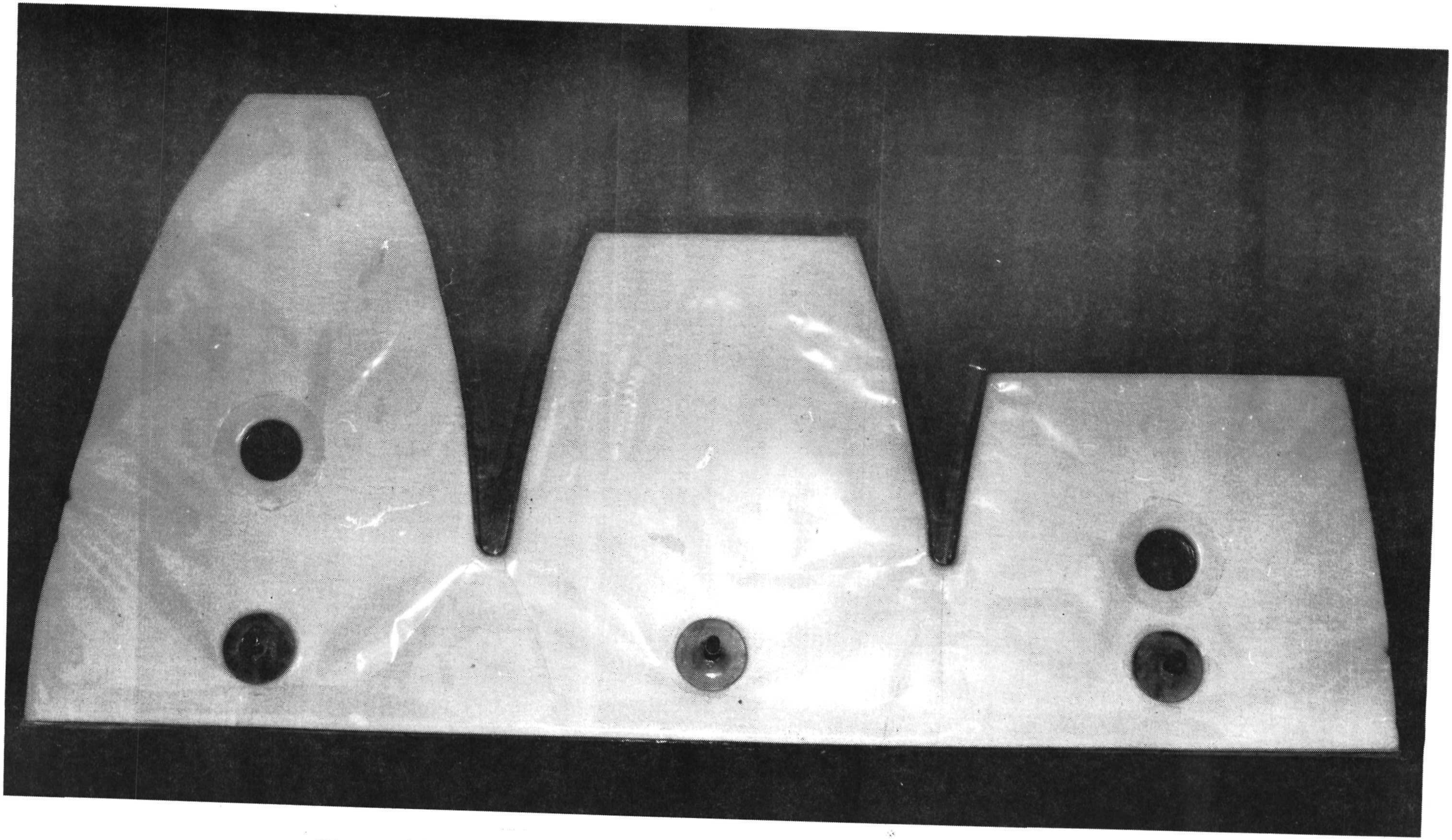


Figure 49 - Completed Large Scale Demonstration Panel

After fabrication was complete, a leak check of the panel revealed a leak rate of 9.31×10^{-4} atm-cc/sec-ft^2 (8.65×10^{-5} atm-cc/sec-m^2). The permeation rate for plain 3 mil polyester film is about 7.84×10^{-4} atm-cc/sec-ft^2 (7.28×10^{-5} atm-cc/sec-m^2). Considering the panel size and accuracy of the test (judged to be about $\pm$ 15%), this is good agreement. It is the conclusion of this task then, that the polyester casing forming and bonding techniques developed can be applied to large scale panel fabrication.

5.0 References

1. CR-72017 - Investigation Of A Lightweight Self Evacuating Prefabricated Multilayer Insulation System For Cryogenic Space Propulsion Stages by L. R. Niendorf and G. E. Nies (NAS 3-6289).

2. CR-72363 - Lightweight Multilayer Insulation System by C. R. Lindquist and G. E. Nies (NAS 3-7953).

3. CR-72856 - Lightweight Modular Multilayer Insulation by G. E. Nies (NAS 3-12045).

4. ASME - Unfired Pressure Vessel Code Section VIII, Division I.

5. Formulas For Stress and Strain, Raymond J. Roark, McGraw-Hill Book Co., 1965.

6. An Introduction to Mechanics of Solids, S. E. Crandall and N. C. Dahl, McGraw-Hill Book Co., 1959.

7. Manual of Steel Construction - 6th Edition, A.I.S.C., 1967.

6.0 Appendices

6.1 Appendix I

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

552-55L-138
20 January 1972

Mr. George E. Nies, Project Manager NAS 3-14366
Linde Division
Union Carbide Corporation
Tonawanda, New York 14150

Dear George:

Provided herein are results of the LH_2 tank insulation analysis you requested and the thermal insulation sample emittance measurements.

The thermal analysis was conducted on a typical hot side H33 vehicle cross-section corresponding to the section location for the proposed tank. The analysis for both $\frac{1}{2}$ and 1 inch vehicle microquartz insulation (Figure I, II & III) shows outer tank insulation temperature not exceeding 150°F. The analysis was conducted using a transient, finite difference computer program operating on the thermal model described in appendix A. This analysis is considered conservative since the vehicle leeward side and internal structural representation, which would have served to further attenuate the Microquartz back face thermal response, were omitted from the model.

The emittance measurements on the samples provided by you are summarized in Table I. The technique and procedure used in making the measurements are a proprietary Grumman system which is described in Reference A. The total maximum error which could occur in this technique has been evaluated at ±8%.

Please let us know if you need any further work in this area or our assistance in your other tasks for the SEMI program.

Sincerely,

GRUMMAN AEROSPACE CORPORATION

Pete Dominguez

PD:pab

6.1 Appendix I

TABLE I METALIZE PLASTIC FILM EMITTANCE

SAMPLE#	TEMP. (°F)	TOTAL HEMISPHERICAL EMITANCE (ϵ_{TH})
1	109	0.037
	356	0.044
2	111	0.037
	257	0.043
3	102	0.039
	347	0.044

Reference A: The Development and Test of a Low to Moderately High Temperature Emissometer; by J. G. Androulakis, Progress in Astronautics and Aeronautics Vol. 20, 1967.

6.1 Appendix I

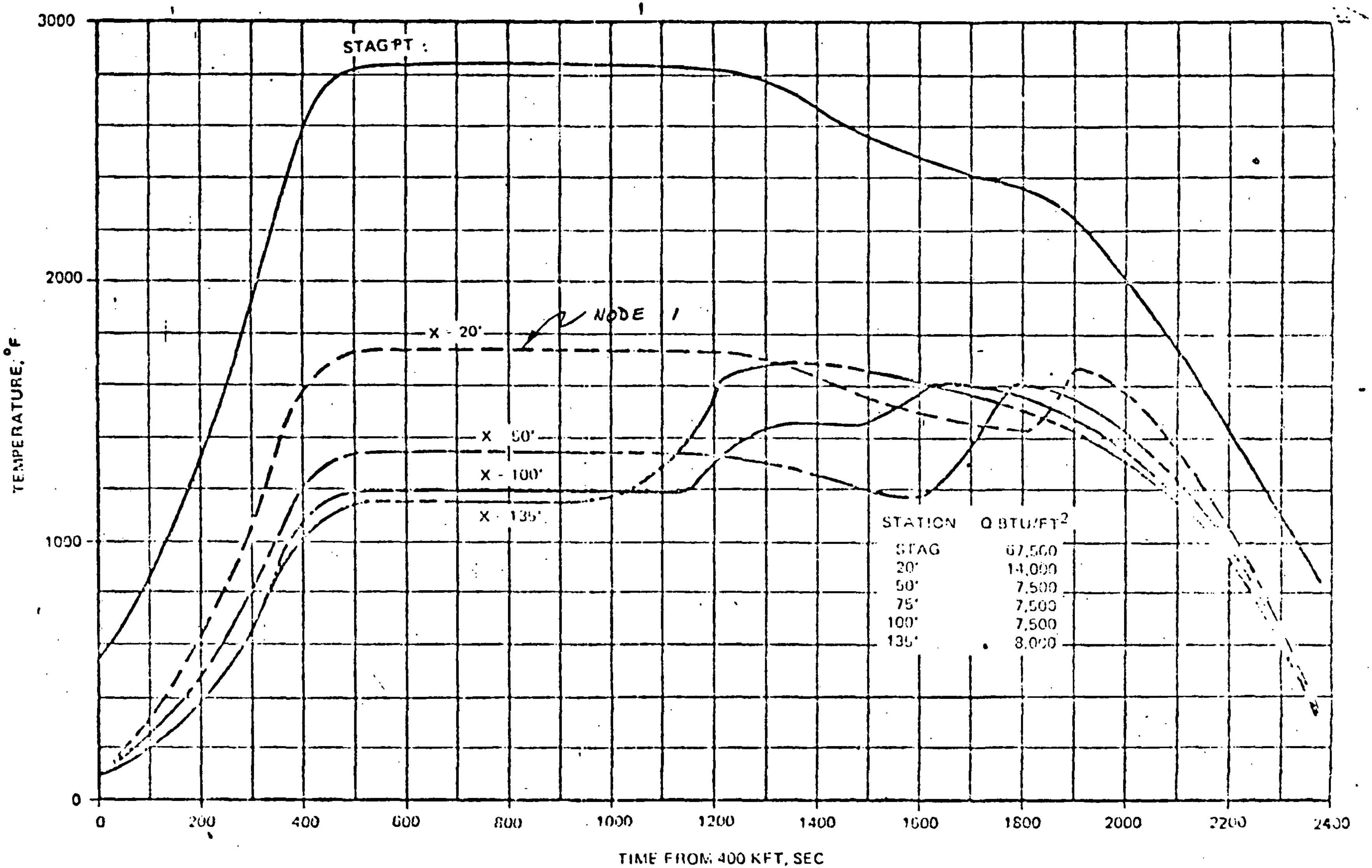
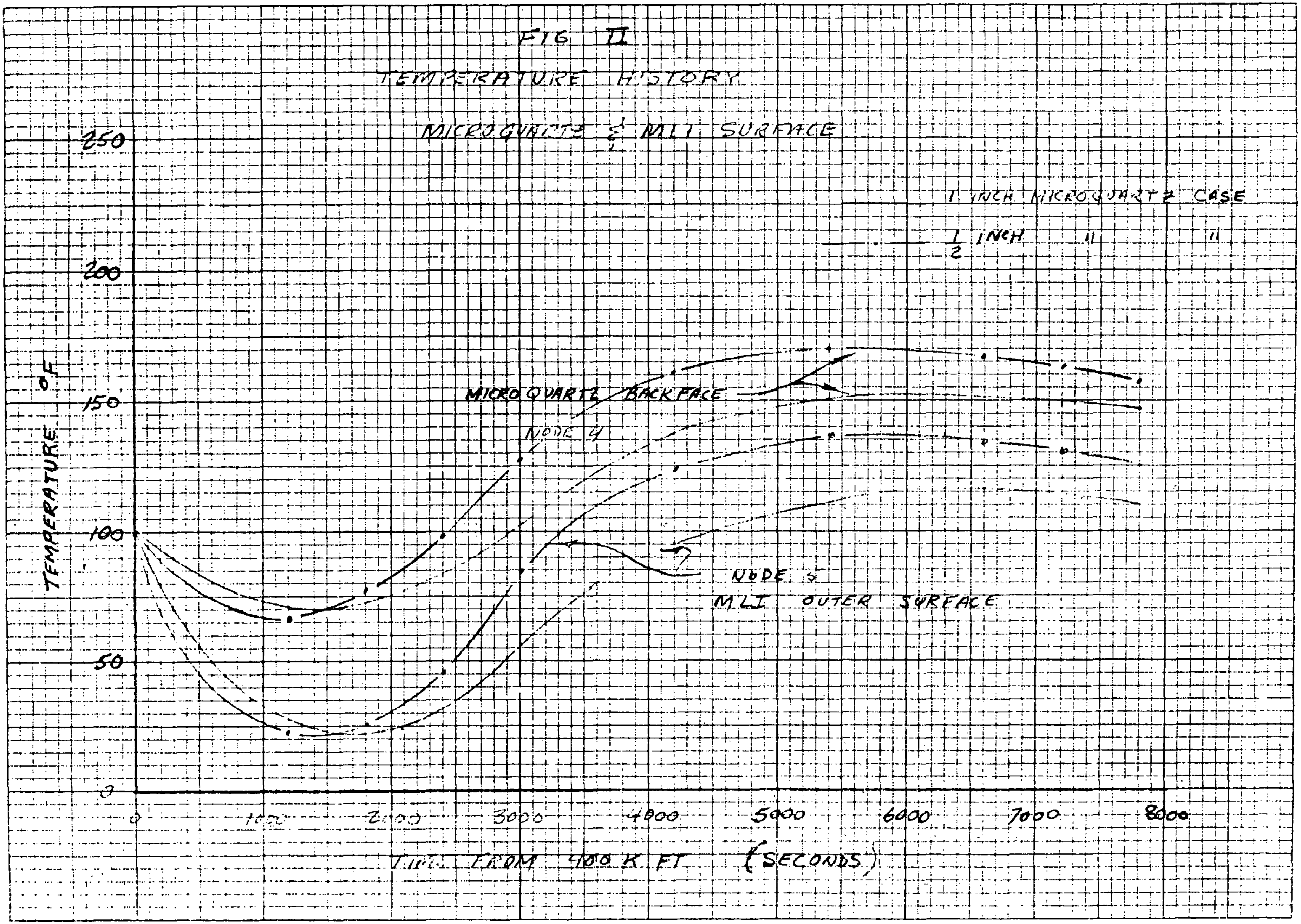


FIG I

H-33 Temperature Time History on Windward Centerline

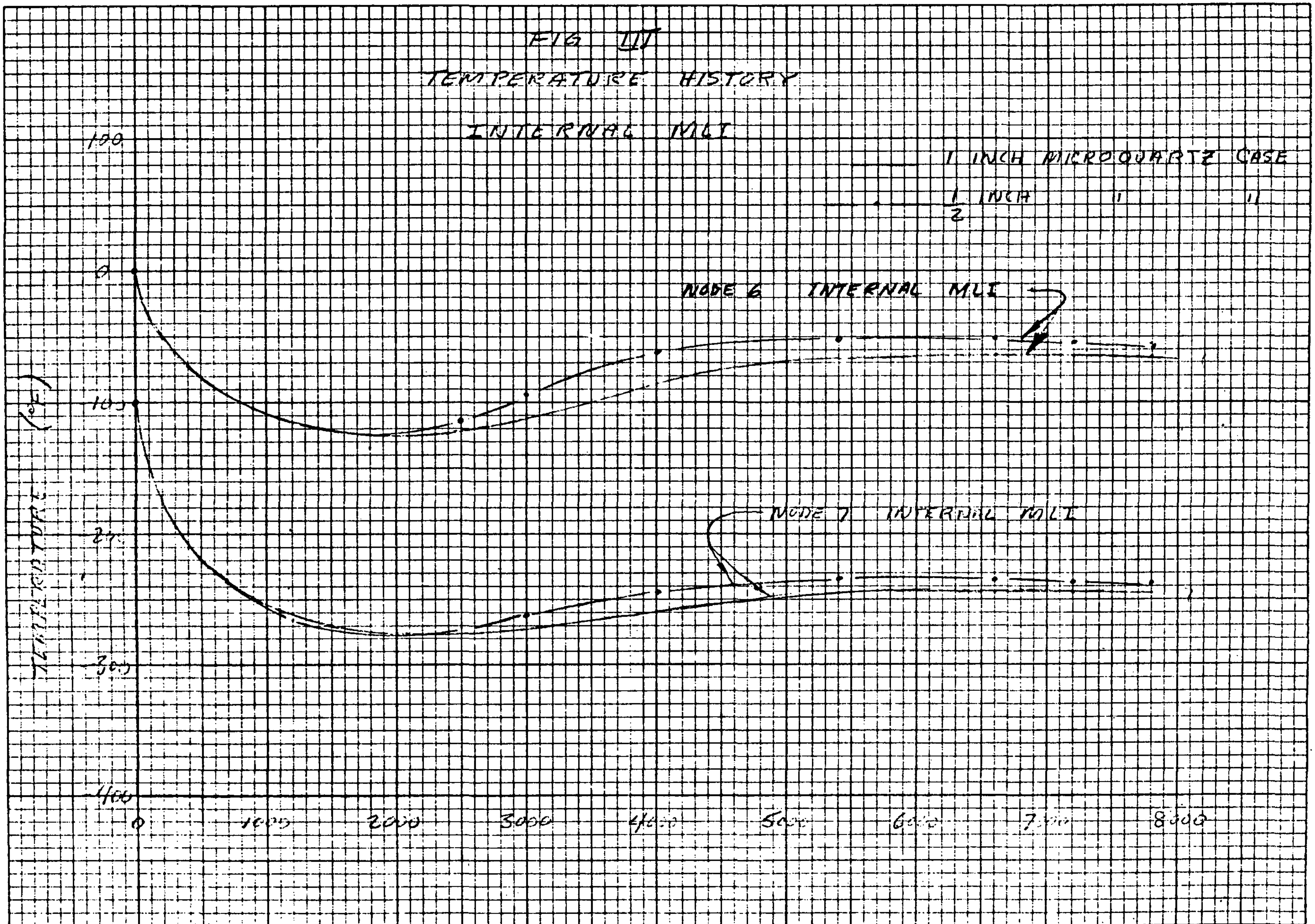
6.1 Appendix I



NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

6.1 Appendix I



6.1 Appendix I

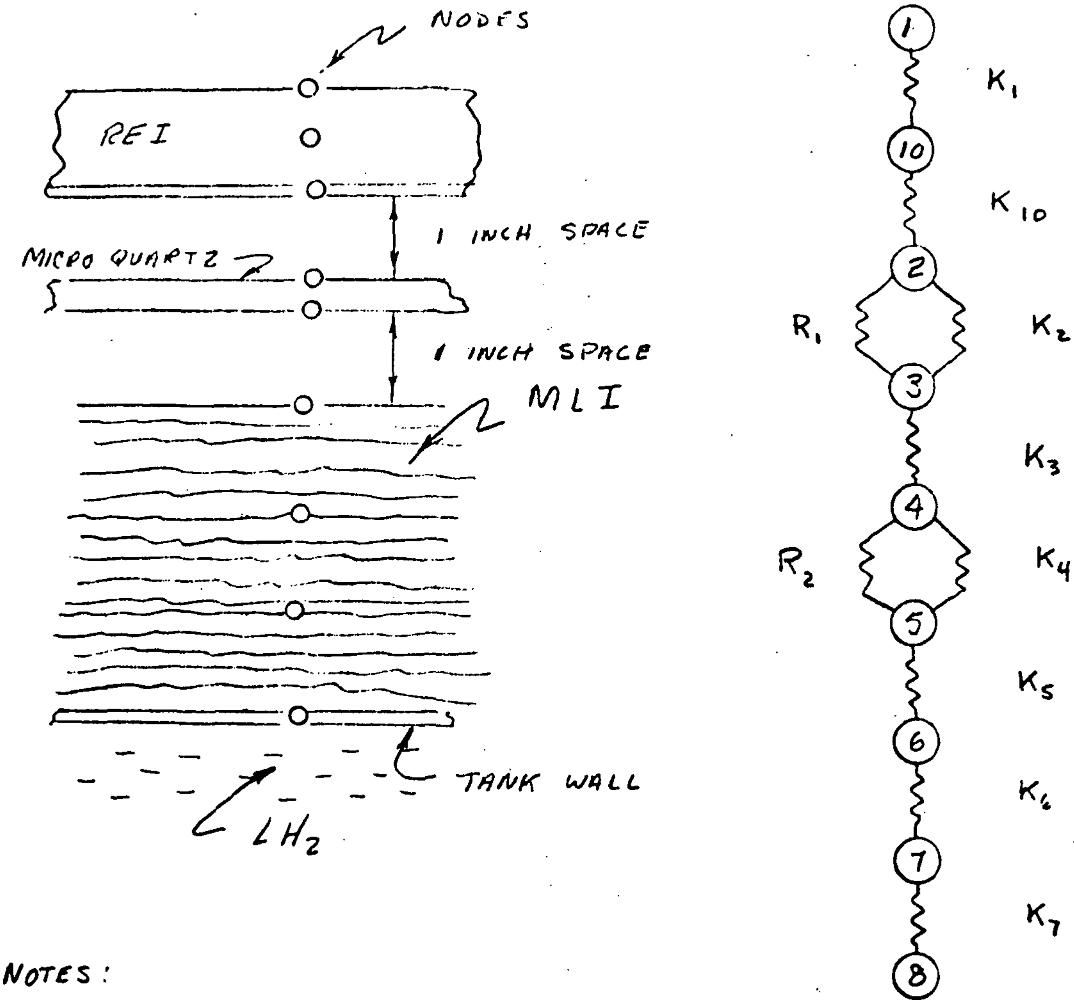
Reference Letter # 552-55L-138

Dated

H33 LH_2 TANK INSULATION ANALYSIS THERMAL MODEL

LINDE CONTRACT #825-79894-C

6.1 Appendix I



NOTES:

K = CONDUCTIVE COUPLINGS

R = RADIATIVE COUPLINGS

FIGURE 1 THERMAL NETWORK MODEL

(ONE DIMENSIONAL, LH_2 TANK LOCATION H33 ORBITER)

6.1 Appendix I

<u>Assumptions:</u>

- One foot square Windward Centerline sectional representation.
- H33 centerline temperature profile for vehicle station 20 ft. from nose tip.
- 2 inch Reusable External Insulation TPS.
- $\frac{1}{2}$ and 1 inch microquartz internal insulation.
- $1\frac{1}{2}$ in Multilayer blanket tank insulation at $.5\#/ft^3$ density.
- Initial temperatures selected to minimize final value effects.

6.1 Appendix I

Network Description

NODES	THERMAL CAPACITANCE (BTU/°F)	COMMENTS
1	N.A. (Boundry)	TPS outer surface
10	0.60	2" REI, C_p = .24 BTU/#°F = 15 #/ft^3
2	0.135	Aluminum Substrate
3	0.0175, 0.035	Micro Quartz, = 3.5#/ft^3 C_p = .24 BTU/#°F
4	0.0175, 0.035	½ and 1 inch respectively
5	0.0052	Multilayer insulation divided into three
6	0.0052	uniform sections
7	0.0052	
8	N.A. (Boundry)	LH_2 tank wall temp = constant

Network Description (Continued)

CONDUCTORS	U VALVE (BTU/SEC°F)	COMMENTS
1	0.6×10^{-4}	REI divide into 2 conductors (1 & 10)
2	See table I	Air gap conduction vs. altitude
3	0.240×10^{-3} 0.120×10^{-3}	Micro Quartz, ½ & 1 inch respectively
4	See table I	Same as 2
5	0.167×10^{-4}	MLI 1.5 in. total Ref = $0.5\#/ft^3$
6	0.167×10^{-4}	
7	0.167×10^{-4}	
10	0.6×10^{-4}	See 1 above

Appendix I

TABLE I

HEAT TRANSFER COEFFICIENT VS TIME (ALTITUDE)

TIME (SEC)	COEF BTU/SEC°F
0	0
40	0
300	$.5999 \times 10^{-5}$
800	$.5999 \times 10^{-5}$
1200	$.6999 \times 10^{-5}$
1400	$.7199 \times 10^{-5}$
2140	$.6599 \times 10^{-5}$
2300	$.6990 \times 10^{-5}$
2400	$.800 \times 10^{-5}$
2600	$.144 \times 10^{-4}$
2660	$.1859 \times 10^{-4}$
8001	$.1859 \times 10^{-4}$

APPENDIX II

Adhesive Assembly Procedures per Manufacturers Literature

Manufacturer/Product Number	Procedure
American Cyanamid Co.	
BXR-34B-32	1. Apply adhesive to film, approximately 1 mil thick. 2. Dry in oven at 200°F. to 250°F. for 10 min. 3. Use shims and press to 1 mil adhesive thickness during cure period of 1 hour at 350°F. NOTE: During the drying stage (Item #2) the adhesive became hard and would crack on bending the Kapton. Also fine or small gas bubbles appeared on the dried film (Dried at temp. 240 to 250°F. for 10 min.). The resulting cured film (1 hr. at 350°F.) also had many small bubbles.
Crest Products Co. - Narmco	
3135-7111 - Epoxy Base, Mixture Resin & Hardener 50:50	1. Apply mixture to both surfaces. 2. Press together with a pressure of 2 psi min. 3. Cure cycle - 24 hrs. at room temp.
3147-7125 - Epoxy Base, Mixture Resin & Hardener 50:50	1. Apply mixture to both surfaces. 2. Press together with a pressure of 2 psi min. 3. Cure cycle - 24 hrs. at room temp.
7343-7139 - Urethane Base, 2 part system, Ratio 100 parts resin to 11 parts curing agent	1. Apply mixture to both surfaces. 2. Press together with a pressure of 2 psi min., for overnight cure to jell stage. 3. Post cure 4 hrs. at 160°F.
7344-7119 - Epoxy Base, 100 parts resin to 14 parts curing agent.	1. Apply mixture to both surfaces. 2. Press together with pressure of 2 psi min., overnight cure at room temp. to jell stage. 3. Cure in oven 1 1/2 hrs. at 200°F.

Manufacturer/Product Number	Procedure
3170/7133 - Epoxy Base Mixture Resin & Catalyst 50:50	1. Apply mixture to both surfaces. 2. Press together and maintain a 2 psi pressure overnight. 3. Post cure 1 hour at 200°F.
Dow Corning	
280A - Silicone Adhesive - Pressure Sensitive, 60 to 62% solid, 1 Part System	Sample #1 - Evaporation of Xylene solvent with heat. 1. Apply adhesive to both surfaces. 2. Allow each piece to dry in the oven 20 min. at 150 to 200°F. 3. Final Cure sample 5 to 6 min. at 300°F. 4. Press the two pieces of Kapton together with 2 psi pressure. Sample #2 - Evaporation of Xylene solvent overnight at room temperature. 1. Apply adhesive to both surfaces. 2. Allow each piece to dry at room temperature overnight. 3. Cure adhesive 5 to 6 min. at 300°F. 4. Press to two pieces of Kapton together with 2 psi pressure.
#732 - Silicone Rubber Adhesive, RTV Type, 1 Part	1. Apply adhesive to both surfaces. 2. Press together with 2 psi pressure and age 24 hr. minimum before subjecting to high temperature test.
3M Co.	
#2214 - Epoxy-Aluminum Filled, 1 Part System.	1. Apply adhesive to both surfaces. 2. Press together at 2 psi minimum. 3. Cure in oven 40 minutes at 250°F. to 260°F. NOTE: Manufacturers' Cure Cycle - 40 min. at 250°F or 30 sec. at 400°F.
EC 3419 Scotch Weld - Epoxy Modified, 1 Part System.	1. Apply adhesive to both surfaces. 2. Press 2 strips together at 2 psi minimum. 3. Oven cure 60 minutes at 350°F. NOTE: Manufacturers' Cure Cycle - Cure Initiation Temp. = 325 to 335°F. Recommended Temp. = 350°F.

Manufacturer/Product Number	Procedure
AF-130 Scotch Weld - Epoxy-Glass Cloth Pre-Preg.	1. Place pre-preg film between 2 sheets of Kapton film. 2. Apply 2 psi pressure to the composite. 3. Heat to 350°F. for a 60 min. cure period. NOTE: Manufacturers' Cure Cycle: Tack Temp. = 120°F. to 180°F. Flow Temp. = 180°F. to 250°F. Cure Initiation = 250°F. to 300°F. Recommended Cure = 360°F. for 60 min.
Matcote Company Inc.	
Matstick 1-02 - Epoxy Base, Ratio: 4 parts Resin to 1 part Curing agent.	1. Apply mixture to both surfaces. 2. Apply 2 psi pressure. 3. Allow to cure 24 hours at room temperature.
Flexible Blend, Bakelite ERL-2774 & Celanese (Jones Dabneg) 858. Ratio: 50:50	1. Apply mixture to both surfaces. 2. Press two sheets together and apply 2 psi pressure. 3. Cure 24 hours at room temperature.
Manufacturer: E. I. DuPont Distributer: American Durafilm Co.	
Teflon - FEP Film - Fluorocarbon	1. Heat metal pressing blocks to 600°F. and repeat at 700°F. 2. Place Teflon (5 mil) film between the Kapton sheets and press for 1 minute at the above temperatures. 3. Examine laminates for adhesion before testing. NOTE: Both samples failed - the fused Teflon did not adhere to the untreated Kapton (Type "H") film.

6.3 Appendix III

TASK IV TEST PLAN

I. TEST OBJECTIVE

The space shuttle as currently conceived will be a multi-trip space vehicle, and as such must be able to withstand the environment of space as well as the atmospheric environment during lift-off and re-entry. The liquid hydrogen tank insulation system for example, must withstand a wide range of temperatures, from cryogenic on the inner panel surface to about 350°F. on the outside panel surface. The insulation panels, when fabricated in unique configurations are expected to withstand the thermal exposure of a 350°F. environment in addition to mechanical cycling due to internal and external pressure changes caused by cryopumping and atmospheric pressure variations during flight.

Subscale testing to be performed on 3-panel insulation systems will include combined thermal exposure and pressure cycling. The test apparatus will be a special subscale tank containing both spherical and cylindrical test surfaces approximating curvatures of actual surfaces. Initially, tests will be conducted at liquid nitrogen temperature, however final testing will be at liquid hydrogen temperature.

II. TEST DESCRIPTION

A combined pressure and thermal cycling test will be performed on a 3-panel insulation system installed on a test vessel having both a spherical surface (simulating a portion of a tank head) and a cylindrical surface (simulating straight tank section). In addition, a protrusion (simulated support rod, fluid line, etc.) will be designed into each surface to allow evaluation of the insulation system around such an area. Two types of penetrations will be investigated, i.e. a rigid type penetration and a semi-rigid type penetration (see Figure 1). Testing will be performed in a vacuum chamber, and the test vessel will contain a cryogen.

6.3 Appendix III

The purpose of the pressure cycling portion of the test is to evaluate the ability of the panels to withstand the cyclic nature of the external pressurer on the panels. During a given flight, the external panel pressure will range from one atmosphere while on earth to vacuum when in space. For testing, the insulation system will be installed in a vacuum chamber. The chamber pressure will then be cycled between one atmosphere and vacuum to simulate atmospheric pressure changes during flight.

The purpose of the thermal exposure test is to evaluate panel configuration for service in the proposed 350°F. environment during re-entry. Previous Task II screening tests provided continuous high temperature (350°F.) data. Task IV testing will provide cyclic temperature data on the panels since the outer skin temperature will be varied from 350°F. to 70°F. while the tank surface is continuously maintained at cryogenic temperature. The panels will be evacuated and sealed off prior to and during the test.

Before the start of testing, the test tank will be evacuated and helium leak checked followed by a hydro-test at 60 psi. After completion of the preliminary tank check out and panel leak checking, the insulation will be installed on the vessel and testing will begin. The insulated test vessel will be placed inside a large (~ 4 ft. dia.) pressure vessel. The outer surface of the panels will be heated to and maintained at 350°F. for 30 minutes to simulate re-entry heat loads. After this time, the external panel temperature will be cooled to ambient temperature and the pressure chamber evacuated for 90 minutes simulating space conditions. During the entire cycle, the cold end of the panels will be maintained at LN_2 temperature. Testing will be conducted for a total of 100 cycles (200 hours) per the Program Plan.

After completion of the 100 cycle LN_2 test, an additional 10 cycle test will be run on the test sections substituting LH_2 for LN_2. The purpose of this additional testing is to determine if any panel degradation occurs due to LH_2

temperature on the cold side of the panels. Testing will be carried out at ambient temperature by cycling the pressure in the panels and between panels with GHe from atmospheric to vacuum.

III. TEST SET-UP AND PROCEDURES

A. Test Vessel Qualification

A sketch of the test vessel is shown in Figure 2. It incorporates a 24 inch spherical surface (inside radius of curvature = 25.6 in.) welded to a 24 in. by 24 in. cylindrical surface (inside radius = 25.6in.). The two surfaces are combined to form a liquid cryogen container fabricated of 304 stainless steel. The vessel will be evacuated, helium leak checked and hydro-tested to 60 psi prior to insulating and testing.

B. Panel Fabrication

The test panel configurations for the two surfaces are shown in Figure 3. The cylindrical surface will be covered by one test panel approximately 2' square, and 2 dummy panels to make up the additional thickness required to simulate a 3-panel system. The spherical surface will incorporate three polar test panels and a single dummy panel. All panels will be fabricated from 2 mil non-metalized Kapton film (type H) and will be bonded with Dow-Corning 732 RTV silicone adhesive. The adhesive will be cured under approximately a 2 psi bonding pressure overnight. All panel-to-panel seals will also be made with the 732 adhesive. All panels, as well as the space behind them, will have an evacuation port installed to allow internal pressure cycling, or leak checking as required.

Panel fabrication will require the design and construction of Kapton stretching forms. The casing materials will be pre-formed using these stretching forms to create good bonding surfaces for the panel seals. The casing material will be draped over the forms and held in place while being heated to 700 - 800°F. under vacuum. After 1/2 hour at temperature, the material will be

quenched with water to produce the permanent set required. Once the casing material has been formed, the 3-layer composite urethane foam spacers (cold side), dexiglass spacers (hot side) and double aluminized Kapton and Mylar shields will be cut.

Each panel will be helium leak checked and an overall permeation rate determined. This rate will be used for comparison with the rate determined at the conclusion of the temperature-pressure cycling tests. A 0.1% Helium in Nitrogen mixture will be used for these permeation tests, to permit evaluation using a Veeco MS-9 leak detector.

C. Penetration Design

Each test surface will have a penetration designed into it. The purpose of the penetration is to simulate piping for vent and fill lines, instrumentation, supports, etc. Two types of penetrations will be incorporated into the design, i.e., a rigid type penetration and a semi-rigid penetration. Each penetration will be attached to the vessel wall using a movable mechanical joint. The joint will be designed so as to limit motion of the penetration to 5^{o}.

In the rigid penetration as shown in Figure 1, a transition casing is bonded onto both the outer penetration vacuum casing and the outer panel surface. It is this casing which flexes allowing for panel movement due to internal or external panel pressure variations. In the semi-rigid penetrations, the vacuum casing is bonded directly to the outer panel surface and movement is taken up by a metal bellows in the penetration vacuum joint. The penetration rod will be moved by hand periodically during the test to simulate movement during flight.

D. Insulation System Installation

All panels will be leak checked prior to installation. The panels will be attached to both the cylindrical and spherical surfaces using VELCRO

fasteners. The overall panel arrangement is shown in Figure 3. The uninsulated portions of the test vessel, i.e., the top, bottom and 2 ends, will be covered with about 4 inches of foam insulation to keep the cryogen boil-off to a minimum. The foam surfaces will then be covered with Dexiglass insulation and then completed with a sheet of casing material. A panel-to-panel seal will be completed between the test panels and the side insulation casing material forming a sealed vacuum system behind the panels. An evacuation port will be located in the outer casing to allow evacuation of this space behind the panels.

After each test surface has been covered and all panel-to-panel seals secured, the space behind the panels will be leak checked and an overall leak rate obtained. A mixture of 0.1% Helium in Nitrogen will also be used for this test.

Thermocouples will be used throughout the test to monitor the temperature of the various panel surfaces. A total of 4 thermocouples will be placed on the panel layers, as shown on Figure 3.

E. Test Procedure

Testing will consist of combined thermal exposure and pressure cycling. The insulation surface will be heated to 350°F. to simulate re-entry heat loads. Then the insulation will be cooled to ambient temperature and the space exterior to the panels will be evacuated simulating space conditions. To accomplish this combined heating and evacuation, the insulated test tank will be placed inside a 4' diameter pressure vessel (see Figure 4). Electric strips heaters attached to metal screen shrouds covering the insulation surfaces will heat the insulation to the desired temperature (350°F). Vacuum pumps will be used to evacuate the test chamber.

Testing will begin by filling the test tank with LN_2. The space behind the panels will then be evacuated as the outer insulation surface is brought to and maintained at 350°F. for 30 minutes. The insulation surface will then be

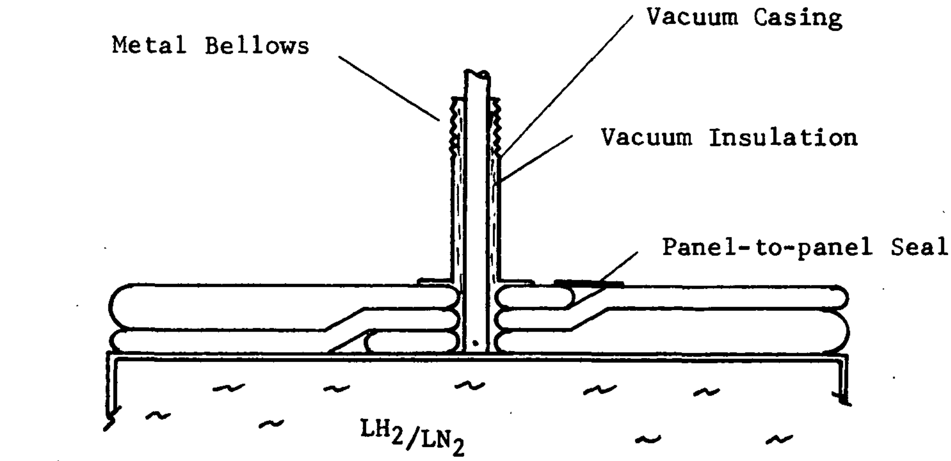
cooled to ambient temperature as the test chamber is evacuated for 90 minutes, thus completing one cycle. The space behind the panel is continuously evacuated throughout the entire test cycle. Testing will continue for a total of 100 cycles. After the 10th, 50th and 100th cycles, panel and panel-to-panel seals will be evaluated for leak tightness. A 0.1% helium in nitrogen mixture will be used for these tests. Any special geometrical conditions such as seams and panel protrusion areas will also be evaluated at these times.

After the 100 cycle LN_2 test has been completed and the post test examination finished, the insulated test tank will be removed from the pressure chamber. Each panel (test panels and dummies) as well as the space behind the panels, will be connected to a vacuum pump. The vessel will be pre-cooled with LN_2 and finally filled with LH_2. The panels and space behind the panels will then be evacuated to simulate cryopumping within the panels. GHe will be used to back-fill the panels to one atmosphere, thus completing one pressure cycle. Testing will continue for ten cycles. It is the purpose of this additional testing to determine whether any panel degradation will occur due to panel flexing at the lower temperatures. Following this test, the panel seals and panel-to-panel seals will again be evaluated for leak tightness.

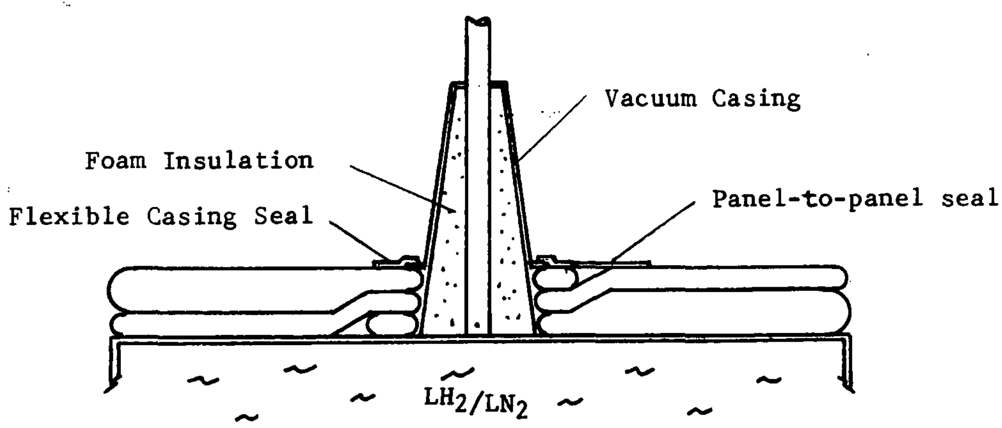
6.3 Appendix III

FIGURE 1

Penetration Seal Design Concepts



Semi-Rigid Penetration



Rigid Penetration

6.3 Appendix III

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

U/M	ITEM NO.	PART OR CODE NO.		MATERIAL AND DESCRIPTION		

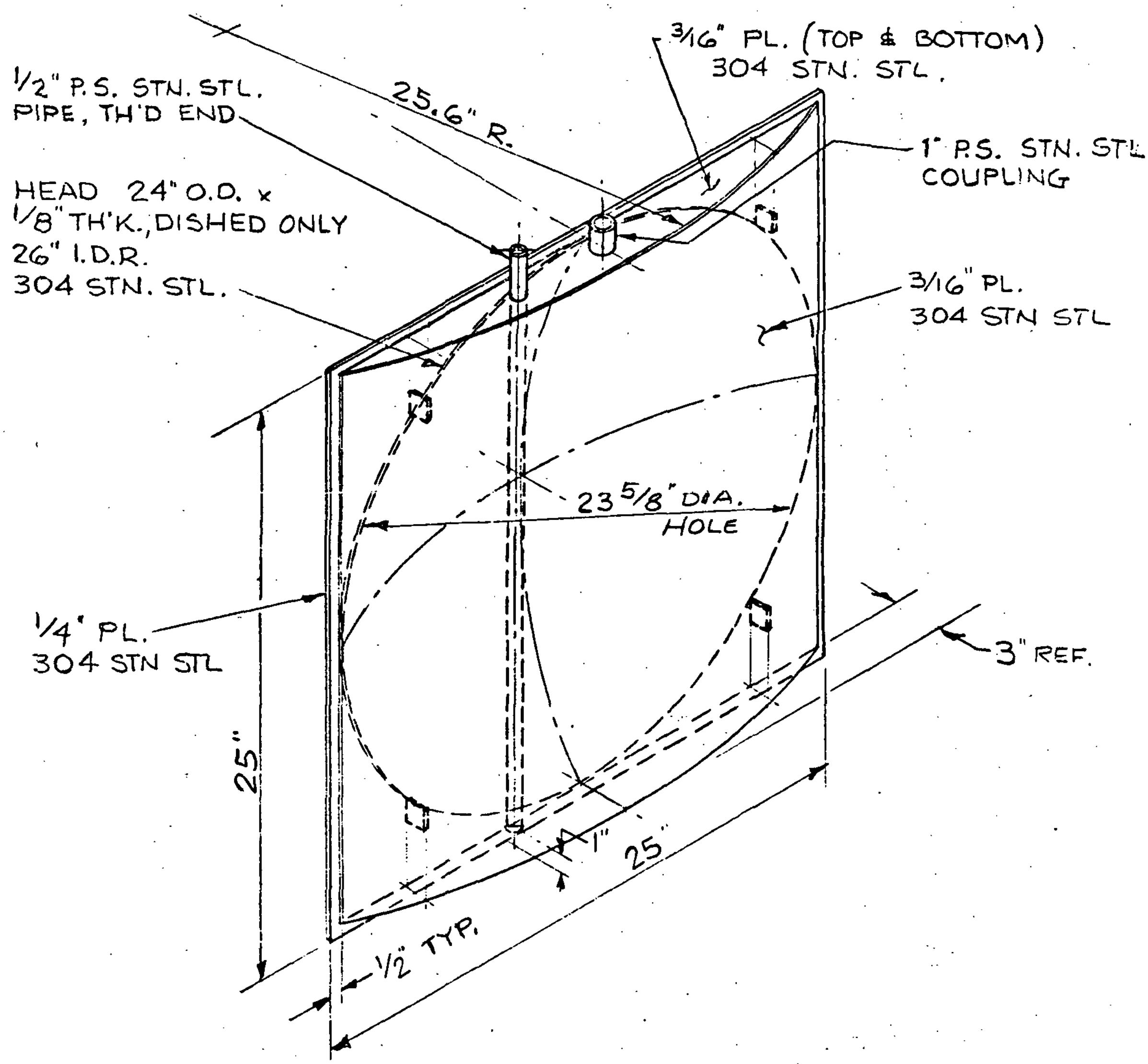


FIGURE 2

TITLE: NASA-LEWIS CONTRACT #3-14366
TASK III TEST VESSEL

TOLERANCES UNLESS OTHERWISE NOTED: .X = ±.1, .XX = ±.06, ANGULAR ± °
MACHINED SURFACES SHALL BE √

SIMILAR TO

BY: | DATE: 10-14-7 | SCALE

CHK'D

APPV'D

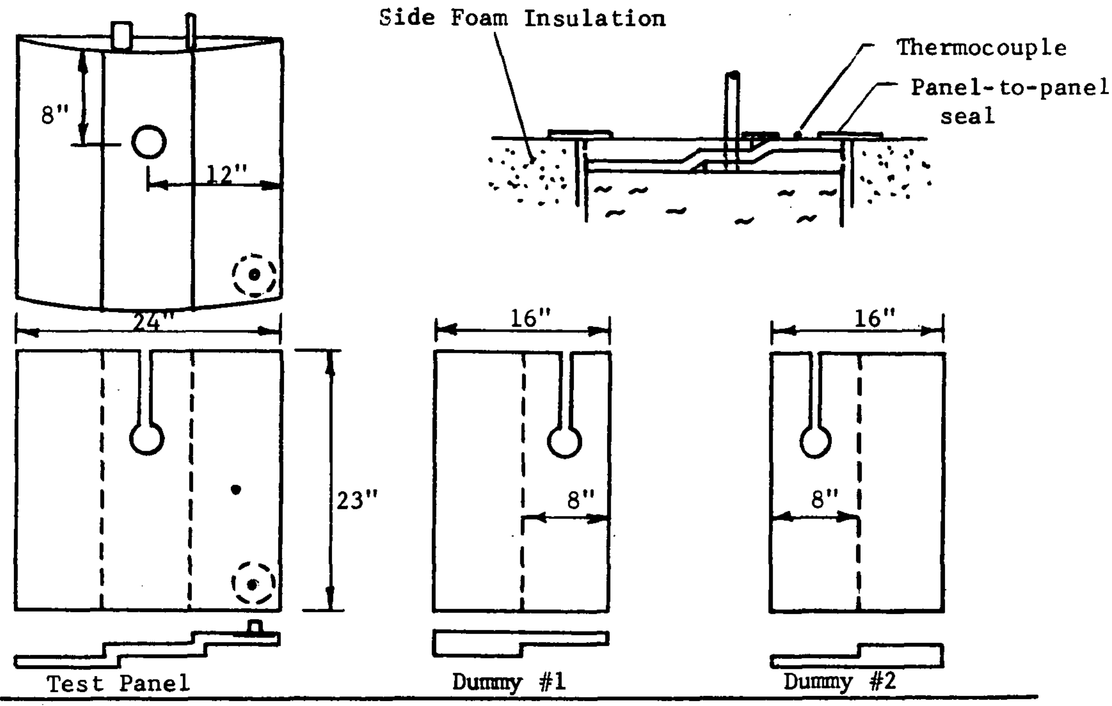
UNION CARBIDE CORPORATION
LINDE DIVISION
TONAWANDA, NEW YORK

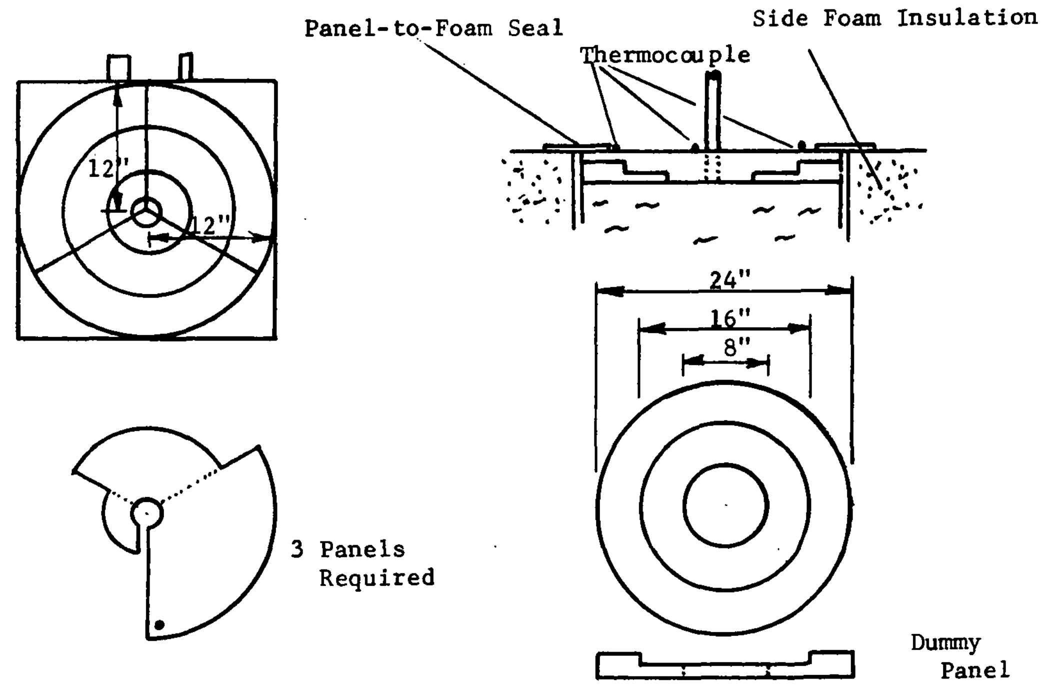
A-SK-108375

FIGURE 3

Panel Configurations

Cylindrical Panel Configuration





Polar Panel Configuration

6.3 Appendix III

1. Cool Test Vessel
2. Evaluate space behind Panels
3. Heat panel surface to 350°F.
4. Evacuate Chamber
5. Cool panel surface to ambient temperature
6. Return chamber to ambient pressure
7. Repeat steps 3-6

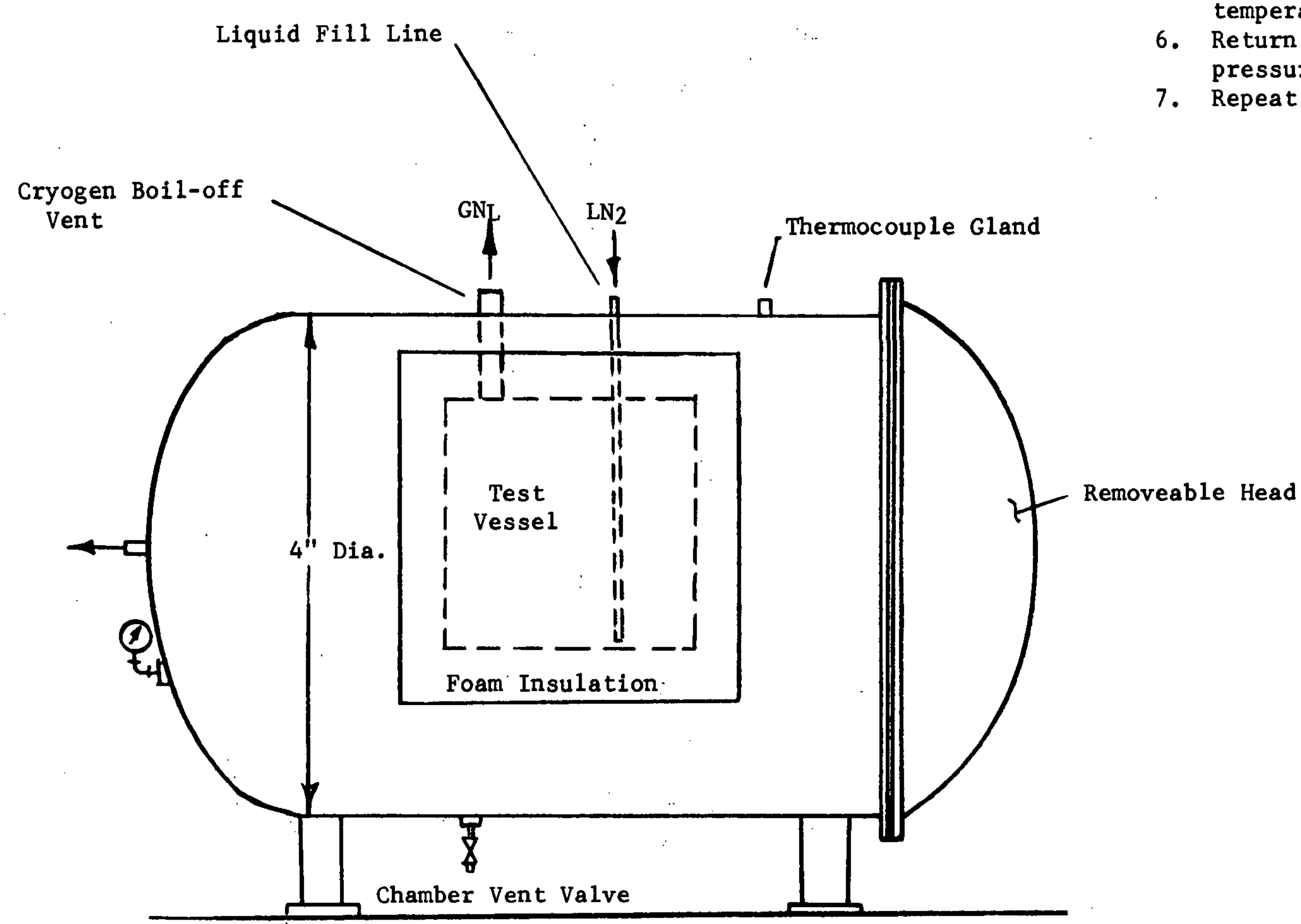


Figure 4

Task IV Test Set-up

APPENDIX IV

CASING MATERIAL PERMEABILITY TESTS *

Casing Material Permeability Tests

Helium permeability tests were performed with the use of the permeability tester shown in Figure 23 of main report combined with a Vecco MS-9 helium mass spectrometer leak detector. The casing material to be tested is cut to a 6 inch diameter disk. This disk is placed between a double set of "O" rings in the permeability tester. The lower "O" ring provides a vacuum seal between the sample and the tester. A porous bronze disk provides support for the casing material sample when one side of the sample is evacuated with the leak detector.

The procedure of conducting a permeability test is as follows: The casing material sample is cut to the required diameter and placed between the "O" rings which are compressed to form a seal by tightening the wing nuts. The permeability tester is then connected to the leak detector and a vacuum is pumped on one side of the sample. When the sample has been pumped to approximately 1×10^{-5} torr, the leak detector scale is zeroed and a standard leak, mounted on the side of the leak detector, is opened into the system, causing the leak detector scale to indicate the number of units proportional to the standard leak. This value is recorded for use in the calculation to determine the sample permeability. The standard leak is then valved off from the system, and it is noted that the detector scale returns to zero. To assure that the lower vacuum "O" ring seal of the permeability tester is not leaking, a spray of helium is put around the outside of this "O" ring. Any leakage, would be immediately indicated on the leak detector scale. After assuring that leakage is not present, a 0.1% helium in nitrogen gas mixture is purged across the top of the casing material sample through the tubing in the top of the permeability tester. When the leak detector scale has reached a steady-state value, this value is recorded and the test is thus completed. To calculate the permeability of the test sample, the following equation is used:

$$\text{Permeability of Sample} \quad \frac{\text{Atm cm}^3}{\text{sec-ft}^2}$$

$$= \frac{\text{Steady-state detector scale reading (units)}}{\text{Standard leak detector scale reading (units)}} \quad \frac{\text{Value of standard leak(Atm cm}^3\text{/sec}}{\text{Area of test sample (ft}^2\text{)}}$$

Note: The above equation assumes use of 100% helium test gas. The actual permeability is inversely proportional to the helium concentration in the test gas.

Example: For a 1% helium test mixture, the actual permeability is 100 times the measured permeability.

* Ref. CR 72856, Appendix 12

6.5 Appendix V

DESIGN REQUIREMENTS TASK VI TEST VESSEL

NOTE - Calculations And Drawings Unchecked. UCC-Linde Accepts No Responsibility For Actions Resulting From Construction Or Testing Based On Them.

GEOMETRY :

a. OVERALL DIAMETER

48 IN.

b. OVERALL LENGTH

72 IN.

c. SUPPORT

TANK WILL BE SUPPORTED BY FOUR GROUPS OF TWO STRUTS EACH.

GENERAL SPECIFICATIONS :

a. TANK OPERATING PRESSURE RANGE

75 PSI INTERNAL TO 15 PSI EXTERNAL

b. TANK OPERATING TEMPERATURE RANGE

AMBIENT TO - 423°F

c. MATERIAL

304 STAINLESS STEEL

d. HEMISPHERICAL HEADS

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
CONTRACT No. NAS 3-14366 TASK VI TEST VESSEL DESIGN CALCULATIONS		KFB		
		APPV'D	SHEET 1	SHEETS
UNION CARBIDE CORPORATION LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, N.Y. 14150		Appendix V		

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6.5 Appendix V

VOLUME CHECK:

INITIALLY WE MUST CHECK THE TANK VOLUME TO DETERMINE THE JURISDICTION OF THE CODE. VESSELS MUST HAVE A NOMINAL WATER CONTAINING CAPACITY OF 120 GAL. OR MORE.

TWO 48 IN. DIAMETER HEMISPHERES

$$V = \frac{4}{3}\frac{\pi D^3}{8} = \frac{(4)(3.14)(48)^3}{(3)(8)} = 57{,}906 \text{ IN}^3$$

ONE 48 IN DIAMETER CYLINDER, 24 IN. LONG

$$V = \frac{\pi D^2 L}{4} = \frac{(3.14)(48)^2(24)}{4} = 10{,}857 \text{ IN}^3$$

TOTAL VOLUME = 68,763 IN^3 = 298 GAL.

$\therefore$ CAPACITY IS WITHIN JURISDICTION OF DIVISION I, SECTION VIII.

SHELL WALL THICKNESS:

DESIGN DATA:

a. EXTERNAL PRESSURE	15 PSI
b. INTERNAL PRESSURE	75 PSI
c. TEMPERATURE RANGE	AMBIENT → −423°F
d. MATERIAL	304 STAINLESS
e. MAXIMUM ALLOWABLE STRESS (TABLE UHA-23, SPEC # SA-240)	18,750 PSI

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
		KFB		
		APPV'D	SHEET	SHEETS
			2	

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LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, N.Y. 14150

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6.5 Appendix V

f. WELD EFFICIENCY 0.7

(TABLE UW-12, NOT RADIOGRAPHED)

FOR INTERNAL PRESSURE (UG-27, pg. 11)

CIRCUMFERENTIAL STRESS (LONGITUDNAL JOINTS)

$$t = PR/SE - 0.6P$$

WHERE

t = MINIMUM REQUIRED THICKNESS

P = MAXIMUM DESIGN PRESSURE

= 75 PSI

R = INSIDE SHELL RADIUS

= 24 IN.

S = MAXIMUM ALLOWABLE STRESS

= 18,750 PSI

E = JOINT EFFICIENCY

= 0.7

SUBSTITUTING

$$t = (75)(24)/(18,750)(0.7) - (0.6)(75)$$

$$= 0.1376 \text{ IN.}$$

FOR EXTERNAL PRESSURE (UG-28, pg. 11)

REFER TO FIGURE UHA-23.1 FOR DETERMINATION OF SHELL THICKNESS UNDER EXTERNAL LOADING

TITLE	REFERENCE	BY KFB DATE	CHK'D	LATEST ALT. LETT.
		APPV'D	SHEET 3	SHEETS

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WHERE

t = MINIMUM REQUIRED SHELL THICKNESS

L = DESIGN LENGTH OF TANK

= DISTANCE BETWEEN HEAD-BEND LINES PLUS ONE-THIRD OF EACH HEAD DEPTH

$= 24'' + \frac{1}{3}(24'') + \frac{1}{3}(24'') = 40$ IN.

D_o = OUTSIDE SHELL DIAMETER

= 48 IN.

P = EXTERNAL DESIGN PRESSURE

= 15 PSI

USING FIGURE UHA-28.1 (SHEET) AND ASSUMING

$t = 3/16$ IN. = 0.1875 IN.

$L/D_o = 40/48 = 0.833$

$D_o/t = 48/0.1875 = 256$

$B = 6500$

P_A = MAXIMUM ALLOWABLE WORKING PRESSURE

$= B/(D_o/t) = 6500/256 = 25.4$ PSI

$\therefore$ A SHELL THICKNESS OF 0.1875 IN. IS WELL CAPABLE OF MEETING THE DESIGN REQUIREMENT OF 15 PSI EXTERNAL LOADING IN ADDITION TO THE 75 PSI INTERNAL LOADING REQUIREMENT.

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
		KFB		
		APPV'D	SHEET 4	SHEETS

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HEAD WALL THICKNESS:

DESIGN DATA: REFER TO SHELL WALL DESIGN DATA

FOR INTERNAL PRESSURE (UG-32, pg.17)

REFERING TO UG-27, pg 11.

$$P = 2SEt/R + 0.2t$$

WHEN $P \leq 0.665\,SE = 0.665\,(18{,}750)(0.7)$

$P \leq 8755$ PSI

SUBSTITUTING AND LETTING $t = 0.1$ IN. (MIN. HEAD TKS.)

$$P_A = (2)(18{,}750)(0.7)(0.1)/(24) + (0.2)(0.1)$$

$$P_A = 109.3 \text{ PSI}$$

FOR EXTERNAL PRESSURE (UG-33, pg.18)

THE PROCEEDURE AS OUTLINED IN UG-28 (d) WILL BE FOLLOWED. NOTATION IS AS FOLLOWS:

t_h = MINIMUM SPHERICAL SHELL THICKNESS

L_1 = SPHERICAL SHELL RADIUS

= 24 IN.

P_A = MAXIMUM ALLOWABLE PRESSURE

$= B/L_1/t_h$

SOLVING FOR THE PARAMETERS REQUIRED OF FIGURE UHA-28.1 (SHEET)

$t_h = 0.1$ IN.

$L_1/100\,t_h = 24/(100)(0.10) = 2.4$

$B = 6700$

$P_A = B/{L_1/t_h} = 6700/240 = 27.9$ PSI

∴ A HEAD THICKNESS OF 0.1 IN. IS CAPABLE OF MEETING BOTH THE INTERNAL AND EXTERNAL PRESSURE DESIGN REQUIREMENTS. USE 3/16", HOWEVER, BECAUSE OF EASIER AVAILABILITY.

WEIGHT OF TANK:

TOTAL MATERIAL VOLUME = VOLUME OF ONE SPHERE + VOLUME OF ONE CYLINDER

ASSUME $t_{HEAD} = 0.1875"$

$t_{SHELL} = 0.1875"$

$$\text{VOLUME} = \frac{1}{6}\pi\left({D'_o}^3 - {D'_i}^3\right) + \frac{\pi L}{4}\left({D''_o}^2 - {D''_i}^2\right)$$

$$= \left(\tfrac{1}{6}\right)(3.14)\left[(48)^3 - (47.625)^3\right] + \frac{(3.14)(24)}{(4)}\left[(48)^2 - (47.625)^2\right]$$

$$= 1346\ \text{IN}^3 + 676\ \text{IN}^3$$

$$= 2022\ \text{IN}^3$$

DENSITY 304 STAINLESS STEEL = 488 LB/FT^3 = 0.282 LB/IN^3

TITLE	REFERENCE	BY DATE KFB	CHK'D	LATEST ALT. LETT.
		APPV'D	SHEET 6	SHEETS

UNION CARBIDE CORPORATION
LINDE DIVISION
ENGINEERING DEPARTMENT
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6.5 Appendix V

1. WEIGHT OF TANK

$$W_T = \rho V$$
$$= (0.282)(2022)$$
$$= 570 \text{ LBm}$$

AREA TO BE COVERED BY INSULATION

$$A = \text{AREA OF 2 HEMISPHERES} + \text{AREA OF CYLINDER}$$
$$= 2 \times 2\pi R^2 + \pi D L$$
$$= (4)(3.14)(24)^2 + (3.14)(48)(24)$$
$$= 10{,}857 \text{ IN}^2$$
$$= 75 \text{ FT}^2$$

DENSITY OF INSULATION $\cong 0.3$ LB/FT³

2. WEIGHT OF INSULATION

$$Wt = \rho V$$
$$= (0.3)(75)$$
$$= 23 \text{ LBm}$$

3. TOTAL TANK WEIGHT

$$Wt = 570 + 23 \cong 600 \text{ lbm}$$

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
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6.6 Appendix VI

DESIGN REQUIREMENTS - TRANSPORTER:

a. TEMPERATURE RANGE

AMBIENT TO +350°F

b. MATERIAL

CARBON STEEL

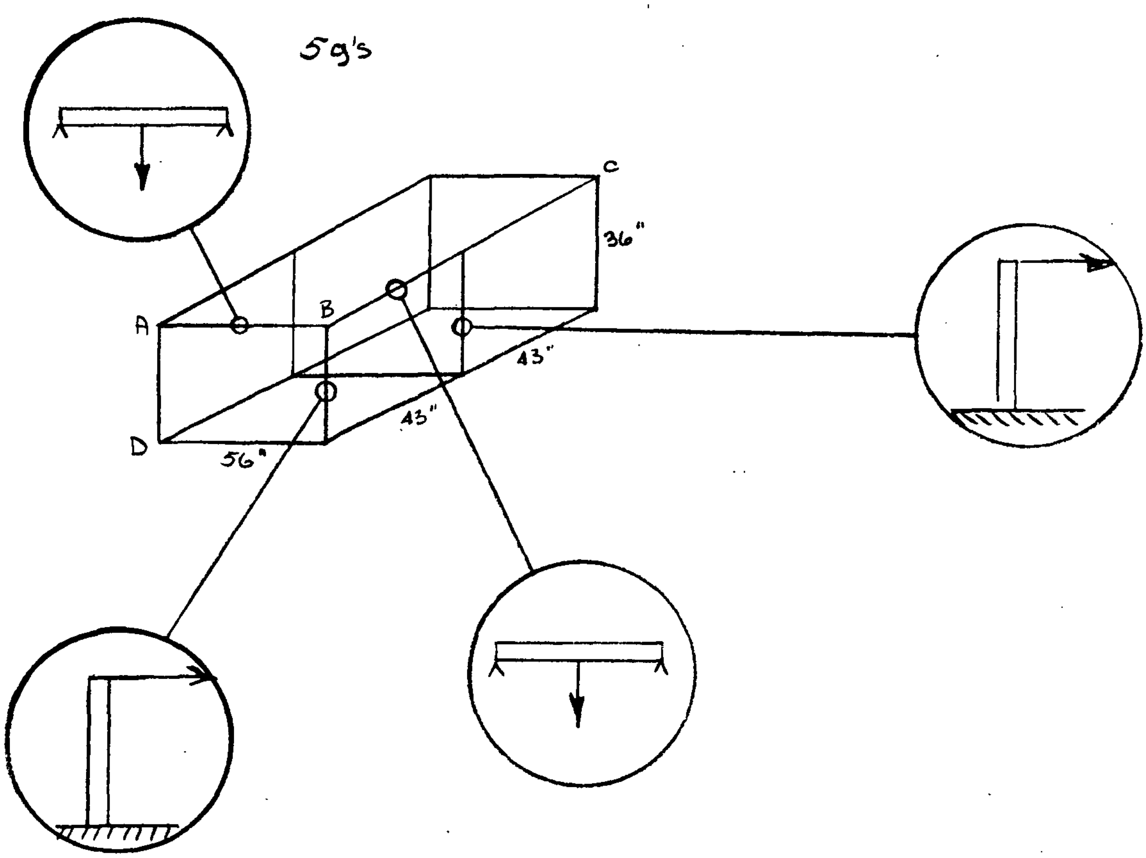
NOTE - Calculations And Drawings Unchecked. UCC-Linde Accepts No Responsibility For Actions Resulting From Construction Or Testing Based On Them.

c. MAXIMUM ALLOWABLE STRESS

20,000 PSI

d. SHOCK LOADING DURING TRANSPORTATION

5 g's



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Appendix VI

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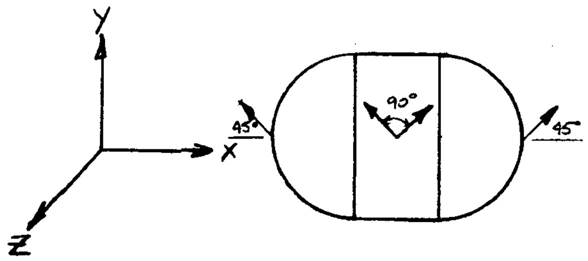
DYNAMIC LOADINGS:

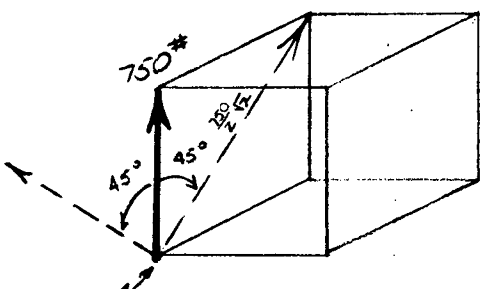


4 GROUPS OF 2 STRUTS EACH

ASSUME THAT DURING TRANSPORTATION, 5g SHOCK LOADS ACT ON THE TANK. FURTHER ASSUME THAT EACH STRUT PAIR CARRIES AN EQUAL LOAD, IE

$$\text{LOAD / STRUT GROUP} = \tfrac{1}{4}(\text{TANK WT} \times 5g)$$
$$= \tfrac{1}{4}(600\#)(5g)$$
$$= 750 \text{ LB}$$

THE STRUT GROUPS ARE 90° FROM EACH OTHER AND 45° FROM THE VERTICAL, IE



THE 750# LOAD AT THE TANK IS BROKEN INTO 2 COMPONENTS, EACH 45° FROM THE ORIGINAL.

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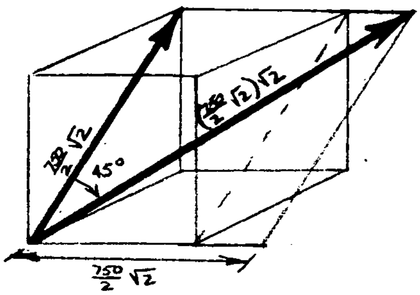

THE 2 COMPONENTS THEN ARE KEPT 90° APART AND ANGLED 45° AWAY FROM THE VERTICAL (OR 45° AWAY FROM TANK)

THE RESULTING FORCE COMPONENT CARRIED BY EACH STRUT IS THEN

$$\text{LOAD} = \left[\left(\frac{750}{2}\right)\sqrt{2}\right]\sqrt{2}$$

$$= 750\ \#$$

THROUGH GEOMETRICAL MANIPULATION, IT CAN BE SHOWN THAT THE 5g LOAD IF APPLIED IN ANY OF THE 3 ⊥ DIRECTIONS WILL RESULT IN A 750# LOAD IN EACH SUPPORT ROD -- ONLY THE DIRECTION OF THE FORCE WILL CHANGE, IE TENSION OR COMPRESSION.

SUMMARY:

① WHEN TOTAL FORCE ACTS DIRECTLY DOWNWARD (Y-DIRECTION), BOTH SETS OF END STRUTS ARE IN TENSION AS ARE BOTH SETS OF SIDE STRUTS

② WHEN TOTAL FORCE (5g × wt.) ACTS IN THE Y-DIRECTION, IE IN TANKS LENGTHWISE DIRECTION, ONE PAIR OF END STRUTS ARE IN TENSION, THE OTHER SET IN COMPRESSION WITH BOTH PAIR OF SIDE STRUTS HAVING ONE MEMBER IN COMPRESSION AND

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ONE MEMBER IN TENSION.

(3) WHEN TOTAL FORCE (5g x wt.) ACTS IN THE Z-DIRECTION, IE IN TANK'S WIDTHWISE DIRECTION, BOTH PAIR OF END STRUTS HAVE ONE MEMBER IN TENSION AND ONE IN COMPRESSION, WHILE ONE PAIR OF SIDE STRUTS IS IN TENSION WITH THE OTHER PAIR IN COMPRESSION.

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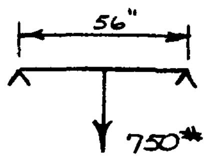
- ASSUME EACH STRUT CARRIES AN EQUAL LOAD, IE 750 #

- ASSUME ALSO THAT LOADS ARE APPLIED ⊥ TO MEMBERS (CONSERVATIVE) INSTEAD OF AT 45° ANGLE

CALCULATION OF LOADS AND DESIGN OF MEMBERS

SHORT HORIZONTAL MEMBER



FROM CASE NO. 11, PG 106 ROARK

$M = \frac{1}{4} WL$

$= \frac{1}{4}(750^{\#})(56")$

$= 10,500$ IN-#

$\sigma_{BENDING} = Mc/I$

$20,000 = (10,500)/I/c$

$I/c = 0.53$

FROM STRUCTURAL SHAPE DATA:

FOR 3" × 3" × 1/4" ANGLE

$\rho = 4.9$ #/FT

$I/c = 0.58$ IN³

$A = 1.44$ IN²

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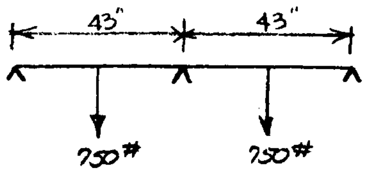
LONG HORIZONTAL MEMBER



ASSUME FULL 750# LOAD ACTS ON BOTH HALVES OF MEMBER

CASE NO. 11, PG 106 ROARK

$M = \frac{1}{4} WL$

$= \frac{1}{4}(750)(43)$

$= 8062$ IN-#

$\sigma_{BENDING} = MC/I$

$90{,}000 = 8062 / I/c$

$I/c = 0.40$

FROM STRUCTURAL SHAPE DATA

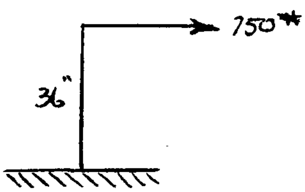
FOR $3'' \times 3'' \times \frac{1}{4}''$ ANGLE

$\rho = 4.9$ #/FT

$I/c = 0.58$ IN^3

$A = 1.44$ IN^2

UPRIGHT CORNER MEMBER



CASE NO. 1, PG 104 ROARK

$M = WL$

$= (750)(36)$

$= 27000$ IN-#

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$\sigma_{BENDING} = MC/I$

$20{,}000 = 27{,}000/(I/c)$

$I/c = 1.3$

FROM STRUCTURAL SHAPE DATA

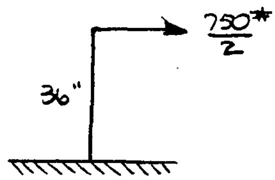
FOR 4"x4"x 3/8" ANGLE

$\rho = 9.8$ #/FT

$I/c = 1.5$ IN^3

$A = 2.86$ IN^2

UPRIGHT CENTER MEMBER



CASE NO. 1, PG 104 ROARK

$M = WL$

$= (750/2)(36)$

$= 13{,}500$ IN-#

$\sigma_{BENDING} = MC/I$

$20{,}000 = (13{,}500)/(I/c)$

$I/c = 0.68$

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FROM STRUCTURAL SHAPE DATA

FOR $3'' \times 3'' \times \frac{1}{4}''$ ANGLE

$\rho = 4.9$ #/FT

$I/c = 0.58$ IN^3

$A = 1.44$ IN^2

SUMMARY:

STRESS LEVELS IN ALL MEMBERS ARE LESS THAN THE 20,000 PSI WHICH WAS ASSUMED AS MAXIMUM ALLOWABLE STRESS. YIELD STRENGTH FOR THE CARBON STEEL IS ~ 40,000 PSI.

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